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Modeling the Fate and Water Quality Impact of the Proposed Dredged Material Placement at Site 104

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WES

Prepared for Maryland Port Administration
and Maryland Environmental Service

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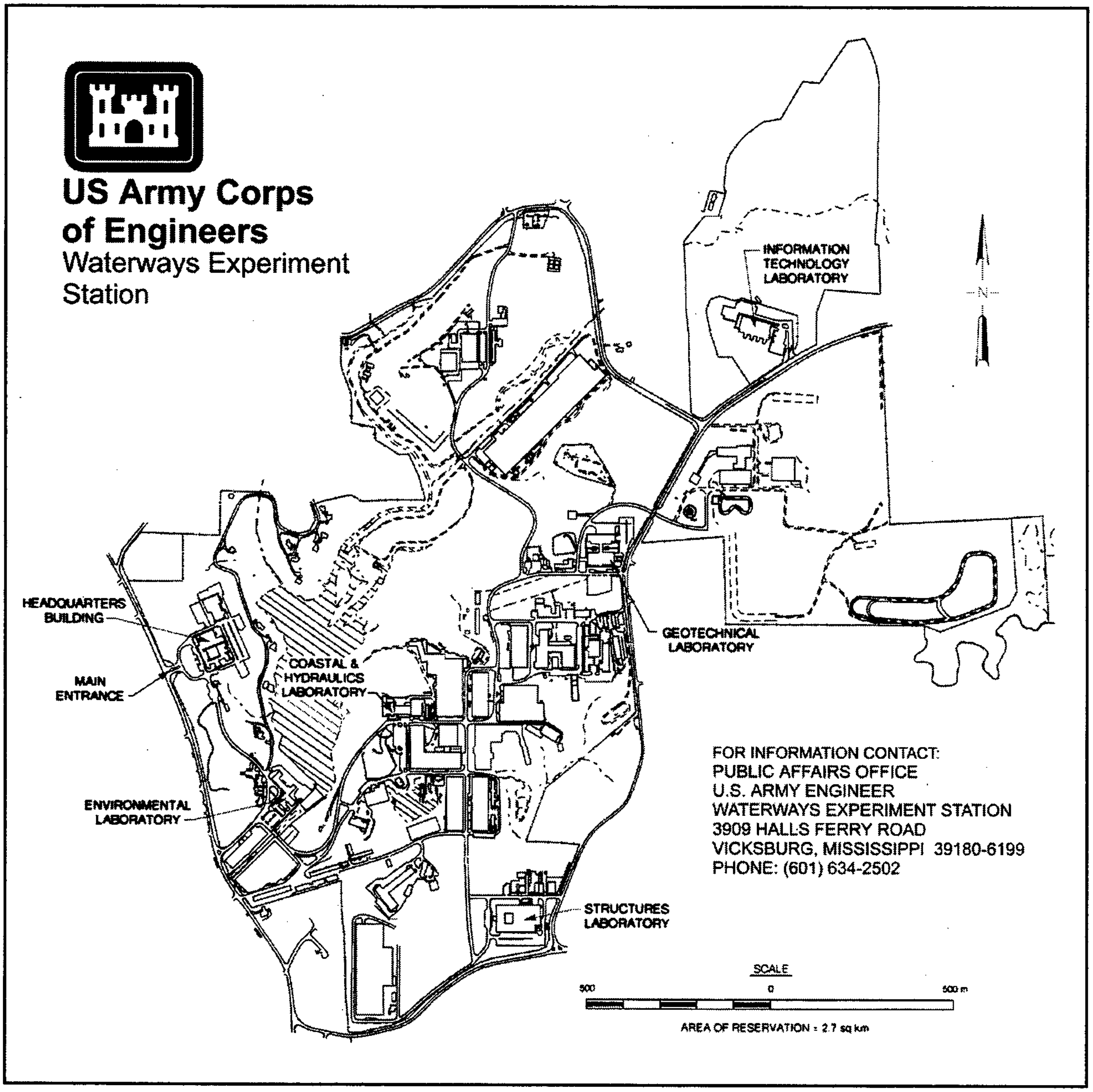

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Preface

The study described herein was conducted during 1997-1998 for the Maryland Port Administration under contract to the Maryland Environmental Service by personnel of the U.S. Army Engineer Waterways Experiment Station (WES) and the U.S. Army Engineer District, Portland. General supervision was provided by Dr. James R. Houston, Director, Coastal and Hydraulics Laboratory (CHL), WES; Mr. Charles C. Calhoun (Retired), Assistant Director, CHL; and Mr. William H. McAnally, Chief, Waterways and Estuaries Division (WD), CHL.

Dr. Billy H. Johnson, WD; Mr. Allen M. Teeter, WD; Dr. Harry V. Wang, WD; Dr. Carl F. Cerco, Environmental Laboratory, WES; and Mr. Hans R. Moritz, U.S. Army Engineer District, Portland, conducted the study and prepared this report for publication by CHL.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers
square feet	0.09290304	square meters

1 Introduction

Site 104 is a previously used open-water, dredged material placement site that is located about 2,000 ft north of the Chesapeake Bay Bridge and 1 mile west of Kent Island. As illustrated in Figure 1, the site is essentially a long rectangle, approximately four and one-half miles long and about one mile wide. Beginning in 1924, the site was used for dredged material placement for a period of 50 years. Before, during, and following its last use in 1975, environmental monitoring was conducted. The monitoring indicated no significant adverse environmental impacts (Site 104 Newsletter 1997).

At the request of the Maryland Port Administration (MPA), the U.S. Army Engineer District, Baltimore, is evaluating Site 104 for placement of approximately 18 million cubic yards (cu yd) of clean dredged material. The dredged material that is proposed for open-water placement at Site 104 will be dredged from Federal navigation channels in the main stem of the Chesapeake Bay, including the Craighill Entrance, Craighill Channel, Craighill Angle, Craighill Upper Range, Cutoff Angle, Brewerton Channel Eastern Extension, Swan Point Channel, Tolchester Channel, and the Southern Approach Channel to the C&D Canal.

Three questions that have been posed in the evaluation of the site are as follows: (a) How much of the material placed at the site has the potential to move out of the site? (b) If material leaves the site, at what location will it be deposited? (c) What will be the water quality impact of placing material at the site? To aid in addressing these questions, the Maryland Environmental Service (MES) under the sponsorship of the MPA requested that the U.S. Army Engineer Waterways Experiment Station (WES) conduct a numerical modeling study. The modeling study utilized existing full bay three-dimensional (3-D) hydrodynamics and water quality models along with a newly developed upper bay 3-D hydrodynamics model. In addition, dredged material placement models developed under the Corps Dredging Research Program were linked to the 3-D hydrodynamics model and applied.

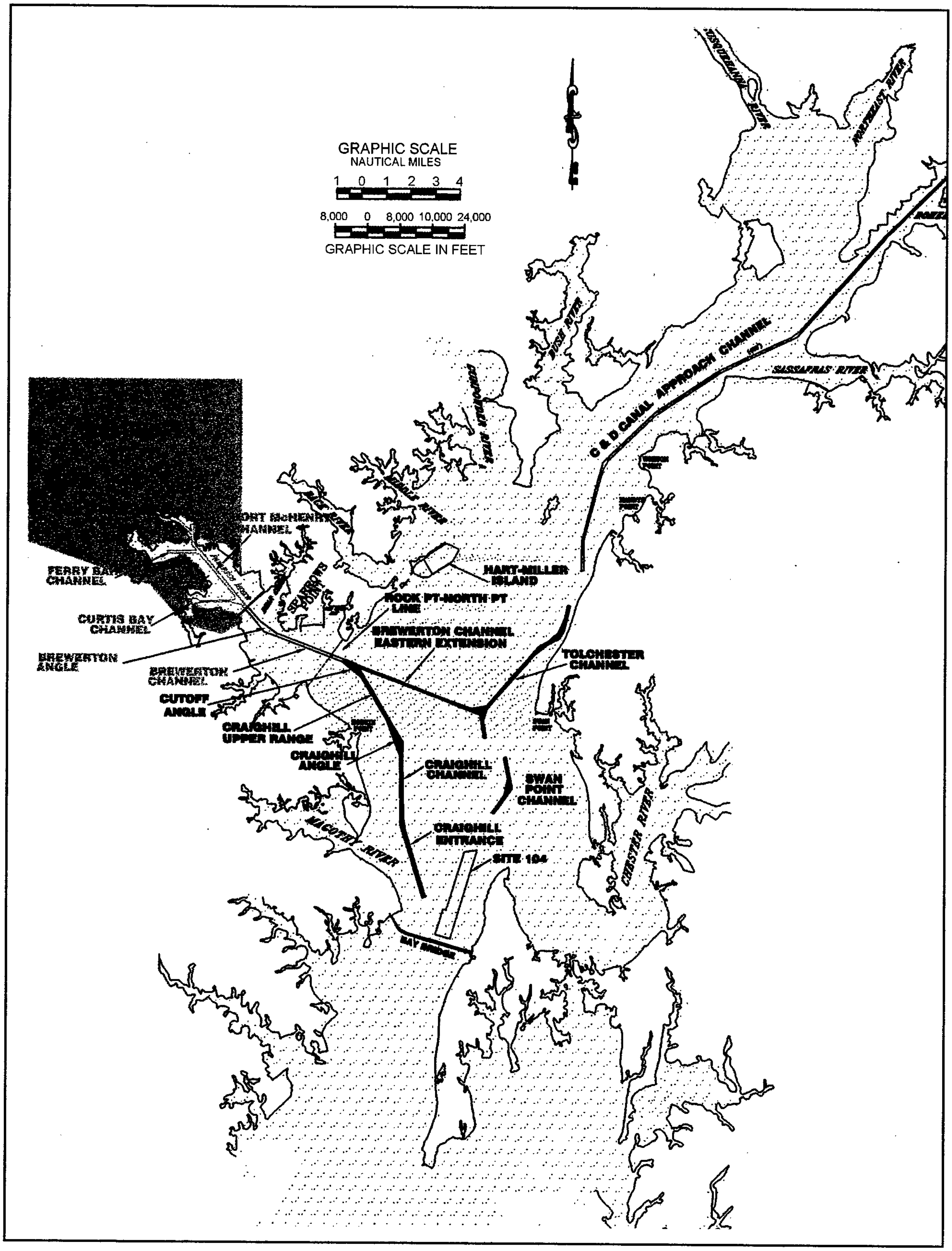

Figure 1. Site 104 and dredged channels map

2 Discussion of Models

The following models have been applied to answer the basic questions of whether dredged material placed at the site has the potential to leave the site and what will the impact be on water quality at the site because of material placement. These models cannot provide information on the question of where material leaving the site ultimately will be deposited. A 3-D hydrodynamic/ sediment-transport model of essentially the entire Chesapeake Bay would be required to answer this question. The development of such a model for the Chesapeake Bay would constitute a major study requiring multiple years of effort. Such an effort was beyond the scope of this study.

CH3D-WES (Curvilinear Hydrodynamics in Three Dimensions)

CH3D-WES is a numerical model for computing 3-D hydrodynamics in coastal, estuarine, and riverine environments. As its name implies, CH3D-WES makes computations on a curvilinear or boundary-fitted planform grid. Physical processes impacting circulation and vertical mixing that are modeled include tides, wind, density effects (salinity and temperature), freshwater inflow, turbulence, and the effect of the earth's rotation.

The boundary-fitted or curvilinear coordinate feature of the model in the horizontal dimensions provides for grid resolution enhancement necessary to adequately represent deep navigation channels and irregular-shoreline configurations of the modeled domain. Two versions of CH3D-WES exist. One utilizes a stretched grid in the vertical to more smoothly represent bottom bathymetry, whereas, the other utilizes a Cartesian or z-plane grid. The z-plane grid enables a more accurate modeling of long-term stratification in deep channels where the horizontal resolution is modest. The z-plane version of CH3D-WES has been employed in previous studies on the Chesapeake Bay. This version is also employed in this study. Details of CH3D-WES can be found in Johnson et al. (1991).

Under the Chesapeake Bay Program, a 3-D hydrodynamic model of the entire Chesapeake Bay and a portion of the continental shelf has been developed. The planform grid of that model is shown in Figure 2. For the Site 104 study, having

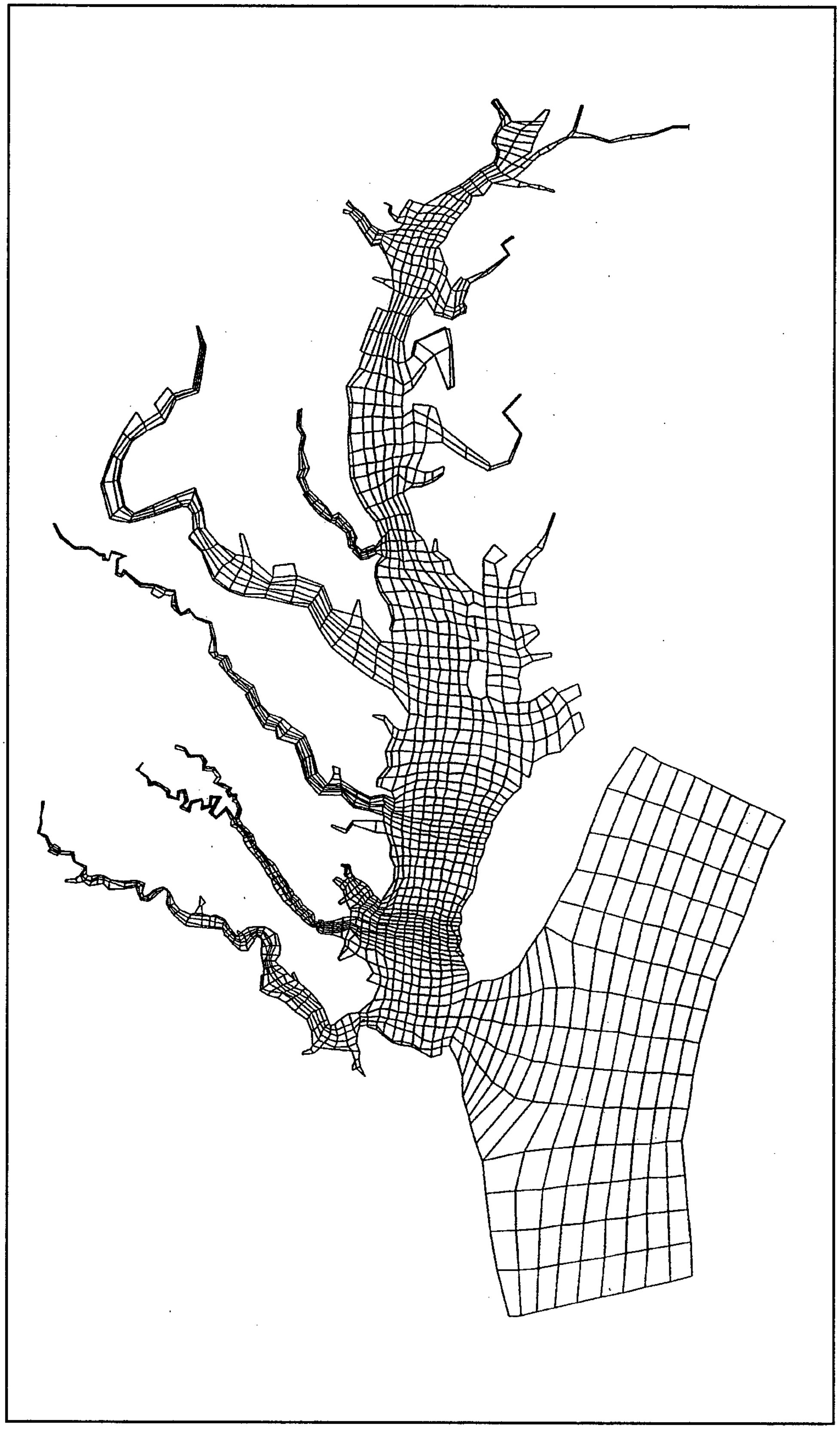

Figure 2. Boundary-fitted planform grid of full bay hydrodynamic model

a much finer resolution was preferred in the upper bay and in particular over Site 104. Therefore, a separate 3-D model was constructed for this study. The planform grid for the upper bay model is illustrated in Figure 3. The vertical resolution in both models contains layers that are 5 ft thick except for the top layer, which varies with the tide. Initially, plans called for driving the southern boundary of the upper bay model with output from the full bay model. However, after settling on the final strategy for the generation of hydrodynamic results, observed data were utilized. These data consist of tides from the National Oceanic and Atmospheric Administration (NOAA) gauges at Annapolis, MD, and near the mouth of the Patuxent River along with salinities obtained from the U.S. Environmental Protection Agency (EPA) Chesapeake Bay Program. Additional discussion of the CH3D-WES application at Site 104 can be found in Chapter 3, Study Approach, and Chapter 6, Hydrodynamic Simulations.

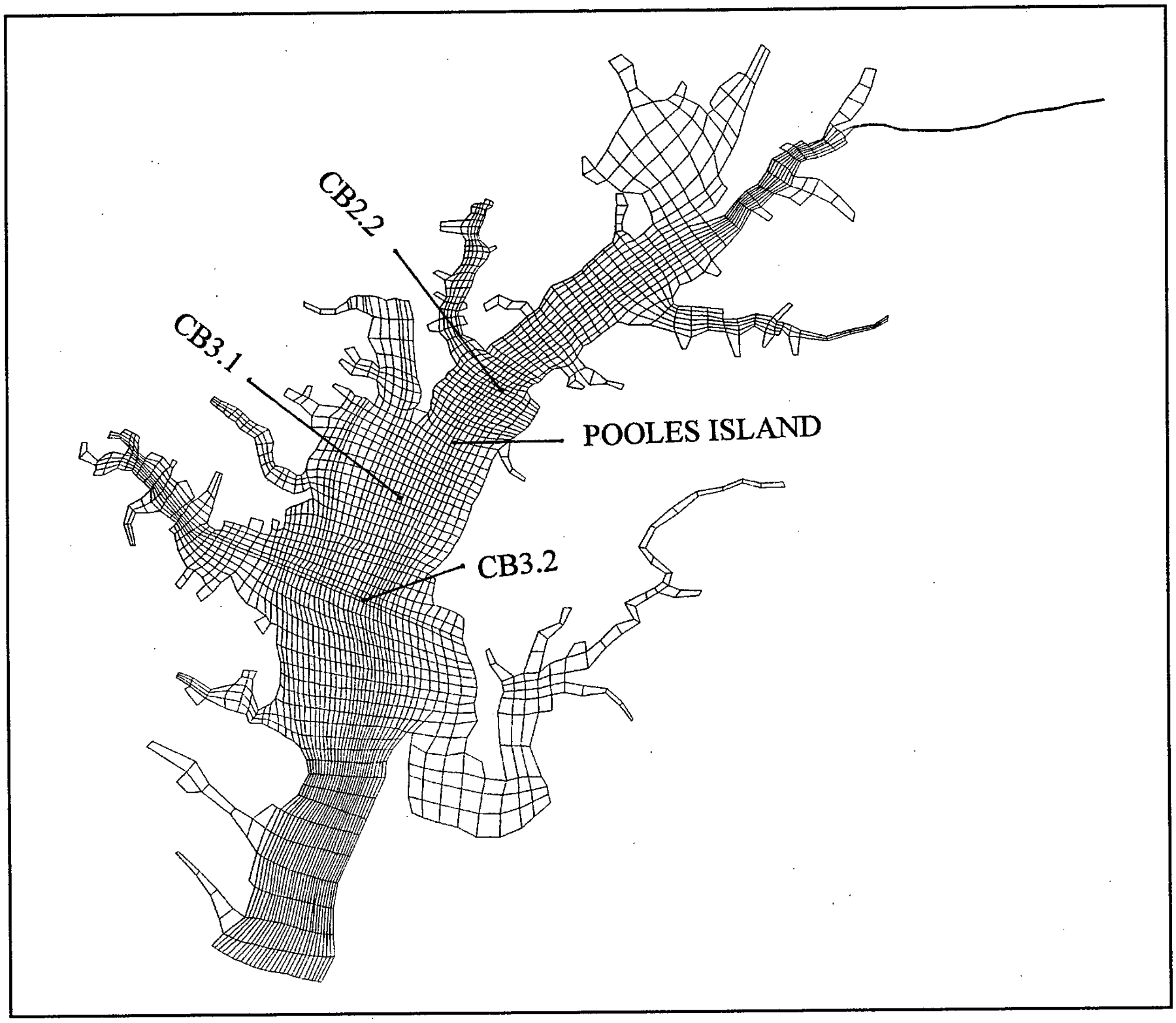

Figure 3. Boundary-fitted grid of upper bay 3-D model (continued)

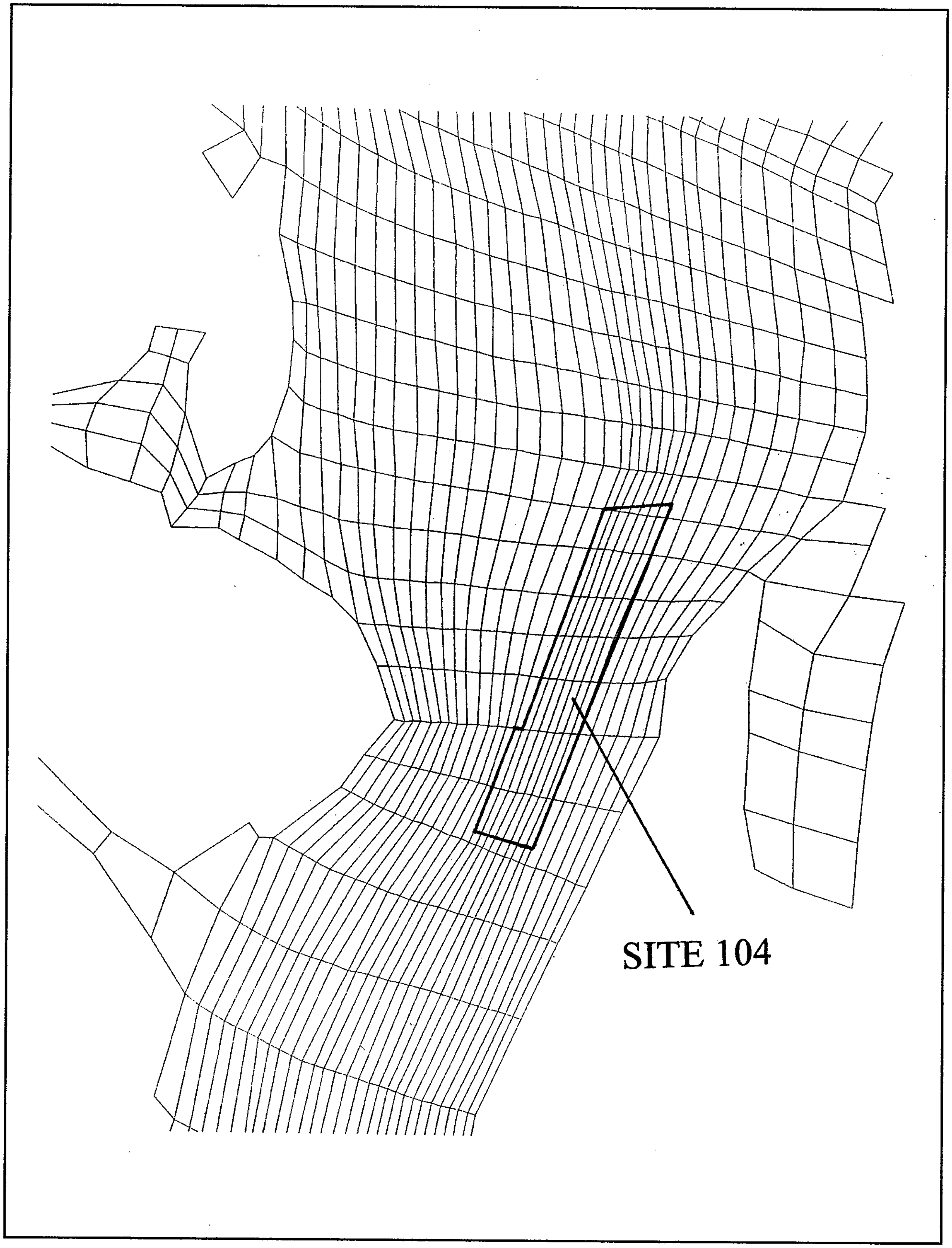

Figure 3. (Concluded)

CEQUAL-ICM (Corps of Engineers Quality-Integrated Compartment Model)

Along with the 3-D hydrodynamic model, under the Chesapeake Bay Program, a 3-D water quality model of the full bay has also been developed (Cerco and Cole 1994). The hydrodynamic model provides the flow fields and diffusion coefficients required for operation of the water quality model. The water quality model computes the fate of quality constituents by summing fluxes across the faces of compartments or finite volume cells. The model calculates 22 state variables. These include components of the nitrogen, carbon, phosphorous, and silica cycles. The end product from the model is a computation for the dissolved oxygen over the water column. The issue of the impact on water quality of placing material within Site 104 was assessed using the CEQUAL-ICM 3-D model. This model was also used to demonstrate that the net transport near the bottom of Site 104 is to the north. This was accomplished by releasing a conservative tracer into the bottom cell overlying Site 104 and then computing the transport and dispersion of the tracer over time. Results are described in Chapter 10, Water Quality Simulations.

STFATE (Short-Term FATE)

STFATE is a model for computing the fate of material placed from either a split-hull barge or a hopper dredge (Johnson and Fong 1995). The model computes the movement of the material from the moment it is injected into the water column until the material is either deposited on the seafloor or transported out of the numerical grid. The computations consist of three phases. The first is the convective descent of the dredged material cloud through the water column, during which the cloud grows as a result of the entrainment of ambient water. During the descent phase, material can be stripped away from the main cloud and, depending on the ambient currents, can be transported varying distances from the release point. Normally, the descending cloud of dredged material strikes the seafloor with a dynamic bottom collapse phase resulting in a radially expanding bottom surge.

A limitation of STFATE in its application at Site 104 is that the collapse is assumed to occur on essentially a flat bottom. This results in a smaller footprint of deposited material on the bottom with a potential for less erosion to be computed by the MDFATE model discussed below. The bottom collapse phase continues until an estimated rate of spreading because of turbulent diffusion exceeds the rate of spreading of the cloud collapse. At the end of collapse, all remaining material is injected into the third phase, which is the passive transport, diffusion, and settling of the suspended material. This phase continues until the material deposits on the seafloor or is transported out of the numerical grid. Basic output from the model consists of information about the amount of material in suspension and the footprint of the deposited material. The STFATE model was employed in this study to provide an estimate of losses to the water column

during descent of the dredged material as a result of placement from a barge or scow. Results are discussed in Chapter 7, STFATE and SURGE Simulations.

MDFATE (Multiple Disposals FATE)

MDFATE is a numerical model that simulates open-water-placement activities with regard to short- and long-term morphology of dredged material placed on the seafloor. MDFATE is intended to be used for planning and managing the use of open-water, dredged material placement sites. A dredging project involving open-water placement of dredged material typically consists of numerous dredged material placements ranging from a few to hundreds or more. The operational duration of such projects can range from days to years. For example, the placement schedule at Site 104 calls for placement of dredged material over a 5-year period with hundreds of individual placements each year. MDFATE was developed to bridge the gap between the modeling of individual placement events and tracking a myriad of placements that occur within a placement site over the duration of the site's operative cycle. For the Site 104 application, the 5-year placement cycle was broken into five 1-year simulations to allow for the impact on hydrodynamics of filling the site. The MDFATE model has evolved from several earlier concepts (Moritz and Randall 1992, 1995).

MDFATE defines an open-water, dredged material disposal site (ODMDS) in terms of a numerical grid and incorporates modified versions of stand-alone computer models to simulate bathymetry change resulting from a series of placement cycles. In this regard, the STFATE (Johnson 1990) and LTFATE (Long-Term FATE) (Scheffner et al. 1995) models are coupled within the MDFATE simulation.

Discretizing an open-water dredged material placement site

As a first step in simulating the life cycle for a given ODMDS or an individual placement operation, MDFATE is used to produce a discretized representation (rectangular digital elevation model) of the ODMDS. The assumption is that the ODMDS is rectangular. All that is required from the user are the ODMDS corner coordinates and the desired grid interval with which to discretize the ODMDS. Horizontal control (x, y) is manifested in terms of the coordinate system used to describe the site in the prototype scale. State plane (ft) and geographic (lat-lng) coordinate systems are supported. Up to 40,000 grid points can be used to represent a given ODMDS in terms of a MDFATE grid. This is sufficient to represent a 20,000- by 20,000-ft placement site with a 100-ft grid interval. Bathymetric (z) data are referenced to a specific vertical datum. Within MDFATE, subsequent modification of an ODMDS's bathymetry is performed with respect to the vertical datum established during the creation of the placement area grid. MDFATE can either automatically generate the ODMDS grid bathymetry (flat or sloping) or adapt survey data

(x, y, z ASCII format) consistent with the actual sites' coordinate system. Survey data are fitted to the MDFATE digital elevation model by a multipoint interpolant scheme. MDFATE is able to produce cross-sectional, 2-D contour, and 3-D surface renderings of an ODMDS grid.

Simulating a dredged material placement operation

Once a particular ODMDS grid has been created, MDFATE can be used to simulate a given placement operation that may extend over 1 year and consist of hundreds of placements. A placement consists of one load of dredged material being mechanically released into open water from either a barge, scow, or a hopper dredge. The entire placement operation is divided into separate week-long episodes over which long-term fate processes governing dredged material behavior on the seafloor are simulated using a modified version of the LTFATE model. Results are modeled in a cumulative manner. Long-term processes include self-weight consolidation, sediment erosion by waves-currents, and mound slumping.

Within each week-long episode, a modified version of STFATE simulates short-term fate processes that govern each placement occurring inside the ODMDS. Short-term processes are those that influence placed dredged material up to the point at which all momentum imparted to the material is expended. The modified STFATE model uses the actual ODMDS bathymetry to simulate cumulative mound distribution arising from each placement. The version of STFATE utilized in MDFATE has been modified to account for the geometric effects of nonuniform bathymetry on the deposition footprint. Although this modification is not physics based, it prevents the initial deposition of placed dredged material in areas shallower than the release point. A prime assumption for the MDFATE model is that other than the placed dredged material, no sedimentary material enters the ODMDS .

In the MDFATE simulation, specification of the placement operation is performed through a menu-driven format in which the user specifies basic data defining the following:

a. Dredging-placement vessel parameterization.

(1) Vessel type (split-hull or hopper), dimensions, and volumetric capacity.

(2) Placement duration per load (time to place each load).

(3) Vessel speed and heading during placement.

(4) Total volume of dredged material to place at the candidate ODMDS during a given operation, or the number of individual placements.

b. Method of control during the placement operation (i.e., positioning of each placement). Four options are available:

   (1) Within a specified radial distance of a predetermined geographic location (i.e., coordinates defining a placement-buoy location). (Placements are placed in a random manner and are weighted in the direction of vessel approach).

   (2) Along a predetermined transect line based on beginning and ending coordinates.

   (3) Each placement location defined by the user entering coordinates.

   (4) Placement locations based upon prerecorded coordinates for each load, i.e., coordinates (x, y) are contained in an ASCII data file queued by MDFATE.

c. Dredged material parameters (density, grain size, solids concentration, voids ratio, shear angle).

d. Site data.

   (1) Existing bathymetry for the candidate ODMDS.

   (2) Time-series data for tidal elevation and tidal-induced depth-averaged currents.

   (3) Time-series data for wind-driven surface waves.

   (4) Ambient depth-averaged current data for residual currents present at the ODMDS.

For modeling purposes, the annual dredging and placement season for ODMDS management is broken into two discrete time periods. For example, dredged material placement at a given ODMDS may begin during the fall time frame and continue until spring. After the spring season, the ODMDS is not used but continues to be affected by the environment until the following fall time frame when placement of dredged-material again commences. The schematic shown below describes how the MDFATE model would be applied to simulate dredged material placement at a candidate ODMDS and account for the seasonality of the ODMDS management.

Placement Simulate Placement Season		Simulate Remaining Part of the Year: Long-Term Fate Only
(1) Model a series of 1-week placement episodes for short-term processes (2) Follow-on with long-term fate calculations for 1 week after each placement episode		Model bathymetric change because of erosion of sediment from the bed and consolidation of the bed
Fall	Spring	Fall
Schematic Time Line for a Dredged Material Placement Cycle at ODMDS.		

Using the above schematic time line as an example, during any given year both short-term and long-term fate processes would be simulated at a site for a 6-month period (fall-spring). Long-term fate processes would then be simulated for a 6-month period (spring-fall) until the following year when the annual cycle begins again. The simulated placement operation is concluded when all placements have been modeled. The specific sequencing of MDFATE simulations for the Site 104 application is described in Chapter 4, Placement Schedules, and Chapter 9, MDFATE Simulations.

Sediment erosion at Site 104

Within MDFATE, the long-term computations are based on a model called LTFATE (Long-Term FATE) (Scheffner et al. 1995). The dredged material can be treated as being either noncohesive or cohesive. In the case of the material to be potentially placed at Site 104, the material is primarily fine-grained cohesive material (silt and clay). MDFATE uses the modified Ariathurai-Partheniades erosion model given below:

$$E = M\,(\tau_b / \tau_c - 1) \text{ if } \tau_b \text{ is larger than } \tau_c \tag{1}$$

$$E = 0.0 \text{ if } \tau_b \text{ is less than } \tau_c$$

where

E = rate of erosion in lb mass/sq ft/hr

M = an erosion rate constant with units of lb mass/sq ft/hr

τ_b = bottom shear stress in lb force/sq ft

τ_c = a critical shear stress for erosion in lb force/sq ft

For conversion to metric units, 1.0 lb force/sq ft = 47.9 Pa and 1.0 lb mass/sq ft/hr = 81.3 g/sq m/min. Although values for M and τ_c can be found in the literature for different types of sediment, one should conduct erosion tests to determine these parameters for the particular material being placed. As will be discussed later (Chapter 5, Erosion Tests), two separate series of erosion tests

have been conducted by the U.S. Army Engineer Waterways Experiment Station (WES) on sediments from the upper Chesapeake Bay channels to be potentially dredged and placed at Site 104. Results from Series II of the erosions tests were used to calculate the values of M and τ_c utilized in the MDFATE model final simulations.

Hydraulic pump out from a barge or scow

In addition to modeling the placement of material at Site 104 from barges or scows, the desire was also to simulate the long-term fate of dredged material that might be hydraulically removed (pumped) from the barge and placed at Site 104. Hydraulic placement from a barge would be accomplished using direct pump out of dredged material. Hydraulic discharge of the dredged sediment would occur through a pipe diffuser located near the estuary bottom to minimize loss of the material to the water column. To simulate a hydraulic- (pump out-) placement scenario, MDFATE was modified to substitute the short-term computations with a computed "footprint" based on a barge or scow pump out operation. The footprint was developed using an approach developed by Thevenot, Prickett, and Kraus (1992) and is discussed in Chapter 8 of this report, Generation of Hydraulic Placement Footprint. The basic assumption is that the hydraulically placed material simultaneously spreads and consolidates on a flat-bottom bathymetry until a critical solids concentration is reached, at which time the material ceases to move.

SURGE

SURGE employs an energy balance concept to determine the extent of a bottom surge (Johnson, internal document, 1997) on variable bottom slopes. Kinetic energy drives the surge and is dissipated because of friction. Potential energy is converted to kinetic energy. The dissipation, rate of entrainment, loss of solids, and the conversion of potential energy to kinetic energy are all set based upon field data collected during the Dredged Material Research Program (Bokuniewicz et al. 1978).

The total kinetic and potential energies available to initiate the surge are obtained from STFATE results at the moment of impact. No spatial representation of the surge is provided by this approach. The basic assumption is that there is a point source of energy that moves along the seafloor until all of the energy has been dissipated.

The SURGE model is used to estimate the maximum lateral extent that some fraction of fine-grained sediments from mechanically placed dredged material might be transported because of the bottom surge. SURGE results are discussed in Chapter 7, STFATE and SURGE Simulations.

3 Study Approach

A critical component of the study was the development of the upper bay 3-D hydrodynamic model (Chapter 6, Hydrodynamic Simulations). Bathymetry in the model grid (Figure 3) was set using NOAA data as well as data from a bathymetric survey over Site 104 conducted by the Baltimore District. Verification of the 3-D hydrodynamic model used salinity and current data collected during October 1992 - October 1993 (Fagerburg 1995) along with data collected in July 1997 (UMCES-HPL)[1] and Hamilton and Boicourt (1984).

Through consultation with MES personnel and others, e.g., personnel from the Maryland Department of Environment, the MPA, and the Baltimore District, the decision was made to use hydrodynamics from the year of 1993 for providing shear stresses and vertically averaged flows to MDFATE. This year was selected from the years of 1985-95 that were available for the Site 104 study because of the large freshwater runoff that occurred during the spring. Such an event will result in larger ebb currents and bottom shear stresses over the site and greater potential for transport through the southern boundary of the site. Data for the years of 1985-95 were available because of the full bay modeling being conducted for the EPA Chesapeake Bay Program.

The initial year of hydrodynamics was run with the existing bathymetry at Site 104 (Figure 4). Figure 4 shows only the southern two-thirds of the site since that is the area of the site proposed for use. Coordinates on Figure 4 (and similar plots in the report) refer to Maryland State Plane Coordinates, North American Datum of 1983. After running MDFATE for the first year of the dredged material placement plan, CH3D-WES was rerun with new bathymetry at the site. These hydrodynamics were then used in the simulation of the second year of the dredging plan. These steps continued until the entire 5 years of the dredging plan were completed. Thus, the effect of dredged material placement within Site 104 (reduction of seabed elevation) is included in the hydrodynamic modeling.

MDFATE was run for each year of the dredging plan assuming both placement from a barge or scow and hydraulic placement as a result of pump out from

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[1] Personal Communication, 1997, L. Sanford, University of Maryland Center for Environmental Studies, Horn Point Laboratory, Cambridge, MD.

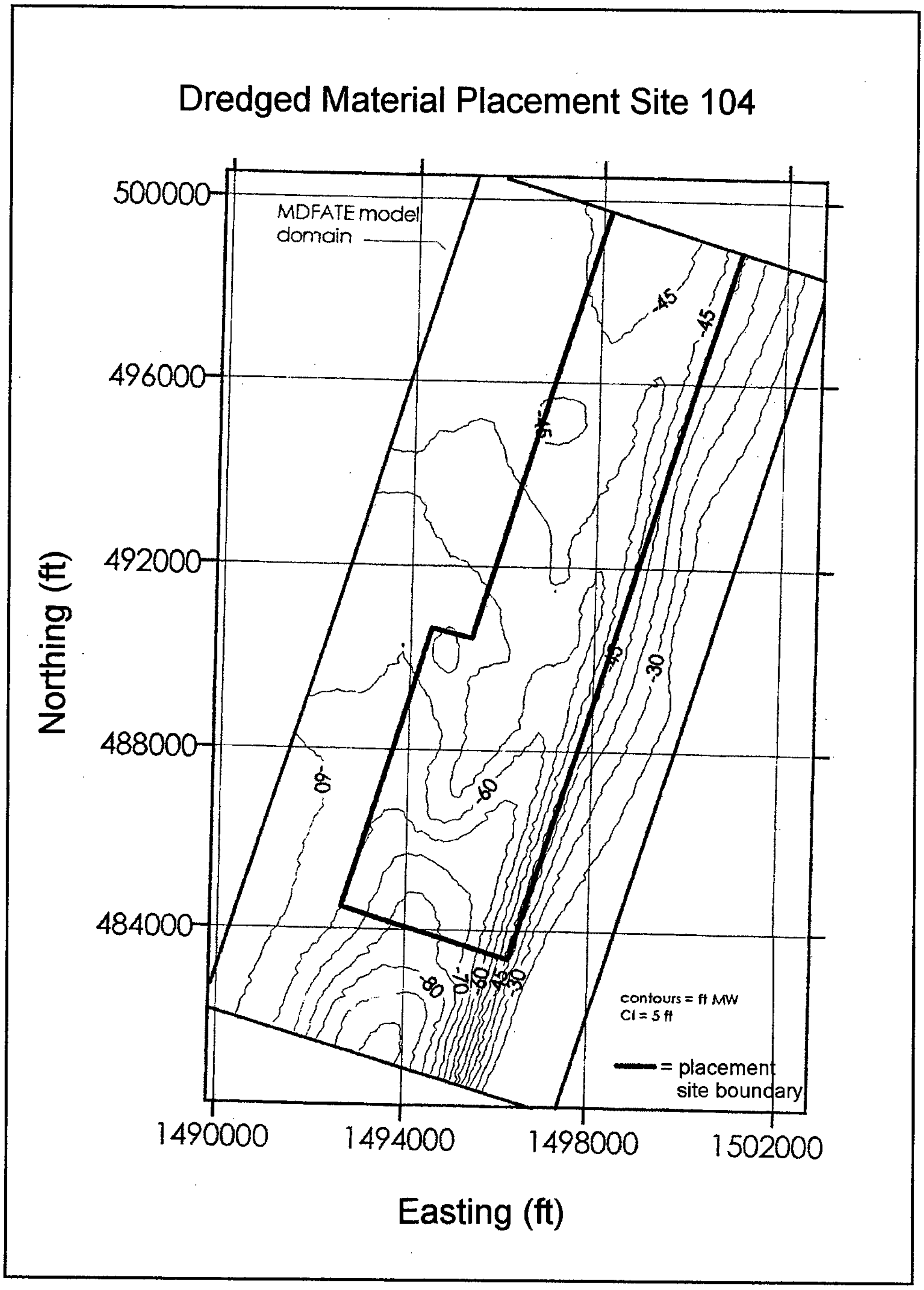


Figure 4. Existing bathymetry at Site 104

a stationary barge. The total volume of material placed varied from 1 year to the next, e.g., the volume placed during the first year was 2.5 million cu yd, whereas, the volume placed in the second year exceeded 4 million cu yd. The annual dredged material placement volumes were based on the State of Maryland's anticipated dredging needs. To maximize the capacity of Site 104 without creating excessively high mounds of placed material, locations of the individual placements were determined using a placement grid. For this study, the output

from MDFATE (at the end of each year simulated) consisted of (a) the new bathymetry at Site 104 and (b) the total mass of dredged material eroded. MDFATE results are described in Chapter 9, MDFATE Simulations.

To provide reliable values for the erosion constants and the critical shear stresses for erosion in the MDFATE model, erosion tests were conducted (Chapter 5, Erosion Tests). Initially, MES provided material from the Swan Point Channel (Figure 1) along with water from the bay for the erosion tests. Later, additional sediment cores from other channels to be dredged, e.g., Craighill Angle, Cutoff Angle, Brewerton Eastern Extension, and Tolchester, were provided to allow for the determination of erosion characteristics representative of the bulk of the material to be dredged.

To provide an estimate of losses to the water column during descent of the dredged material as a result of placement from a barge or scow, STFATE runs were made (Chapter 7, STFATE and SURGE Simulations). These tests were made for several water depths representative of the depths within Site 104. Existing depths at Site 104 range from 42 to 78 ft.

Neither STFATE nor MDFATE allows for a bottom-slope effect when computing the extent of the bottom surge in terms of the physics of bottom encounter. Possibly, placement of dredged material near the boundaries of Site 104 might result in some transport of material out of the site because of the bottom surge created after the material strikes the bottom. The SURGE model was applied assuming several bottom slopes to provide estimates of the extent of bottom surges (Chapter 7, STFATE and SURGE Simulations). However, these results do not provide information on how much dredged material might be transported out of the site during placement or how much material might be carried back in during reversal of the tidal current. As discussed in Chapter 4, placement locations were selected to minimize movement of material from the site.

In addition to the issue of the fate of dredged material placed at the site, the issue of the impact on water quality of placing material within Site 104 was also addressed. In connection with the full bay modeling effort, 3-D hydrodynamics and nutrients loads have been developed for the years of 1985, 1986, and 1987 for the CEQUAL-ICM 3-D water quality model (Chapter 10, Water Quality Simulations). To simulate 5 years of placement operations, a 5-year sequence was constructed using 1985, 1986, 1987, and then 1985 and 1986 again. Three runs were made with the full bay model; namely, a "base run" and runs representative of "no direct release" of nutrients from the placement material into the water column and "complete direct release" of nutrients into the water column. Because of the coarseness of the full bay grid, Site 104 is represented by only one cell in the full bay CEQUAL-ICM 3-D model. A 3-D water quality model on the upper bay grid shown in Figure 3 does not exist. However, the use of the full bay coarse grid model is not believed to be a serious limitation since the model is being used to assess relative impacts.

The "base run" water quality simulation was for the case of no material being placed. The "no direct release" simulation was made with the sediment characteristics in the cell covering Site 104 being continually replaced by an average of the sediment characteristics in cells representing the dredged channels. The "no direct release" simulation represented no elutriation. The "complete direct release" simulation was made with the sediment from the cells representing dredged channels placed into the water column over Site 104, resulting in the release of nutrients directly into the water column. The "complete direct release" simulation represented complete elutriation. The behavior of an actual placement operation lies somewhere between the cases of no elutriation and complete elutriation. These simulations represent the limiting cases.

To provide insight into the effect of bottom residual currents near the site, the water quality model was run with a tracer released in the bottom cell covering Site 104. In one case, the tracer was conservative; in the other case, a settling velocity was attached to the tracer. For the conservative case, the total amount of tracer released remains in the water column. For the case of settling, tracer is removed from the water column at the rate of the settling velocity times the area of the cell. It should be noted that this simulation does not actually model the transport of suspended sediment eroded at Site 104 since sediment deposition is dependent on a critical shear stress for deposition. That process is not modeled in the water quality model.

4 Placement Schedules

As determined by the current State of Maryland Strategic Plan for Dredged Material Placement, the placement of approximately 18 million cu yd at Site 104 is assumed to take place over 5 years, with dredging initiated on 1 November of each year and continuing through March. As previously noted, the locations for the placement of the material were determined to best utilize the site capacity while providing a buffer at the boundaries of the site to minimize loss of material. Site capacity can be defined as the quantity of material that can be placed within the legally designated placement site without extending beyond the site boundaries or interfering with navigation or resources (Poindexter-Rollings 1990). Within the context of this investigation, development of a plan for dredged material placement was performed according to the requirement of meeting the site-capacity constraints.

Placement locations were determined under the assumption that 18 million cu yd of dredged material will be placed over 5 years according to the schedule shown in Table 1. The placement duration was determined by assuming that Years 1, 3, and 5 would have five placements each day (each placement is 3,600 cu yd) and Years 2 and 4 would have ten placements each day. The placement grid (Figure 5) partitions the placement area into 240 cells, each with dimensions of 300 by 500 ft (long axis oriented N-S). The placement grid included a 500-ft buffer along the east and west perimeter and a 1,200-ft buffer along the southern perimeter of Site 104. This buffer is intended to prevent transport of dredged material (by currents or bottom surge motion) beyond the formal site boundary during placement operations.

The placement grid serves as a template for controlling the release point for each load of dredged material, promotes uniform areal distribution of placed material, and minimizes mounding. Initially, a "highly uniform" placement of the material was assumed for Year 1 (Figure 6). However, the "highly uniform" placement plan resulted in increased erosion of placed material because of the large surface area of the dredged material accumulation. Therefore, the development of placement locations for each year of simulated dredged material placement was "modified" to minimize both vertical accumulation on the estuary bed and surface area of accumulation. The "modified" placement plans for each year are shown in Figures 7-11. These locations were used in MDFATE in the simulation of dredged material placement for both the conventional barge and the

Table 1
Placement Volumes and Duration

Year	Dredged Material Volume cu yd	Placement Duration (Days starting from Nov 1)
1	2,502,000	139
2	4,500,000	125
3	3,024,000	168
4	6,048,000	168
5	2,016,000	112

hydraulic placement methods. One should refer to Chapter 9, MDFATE Simulations, for additional discussion regarding development of the "modified" placement plan concept.

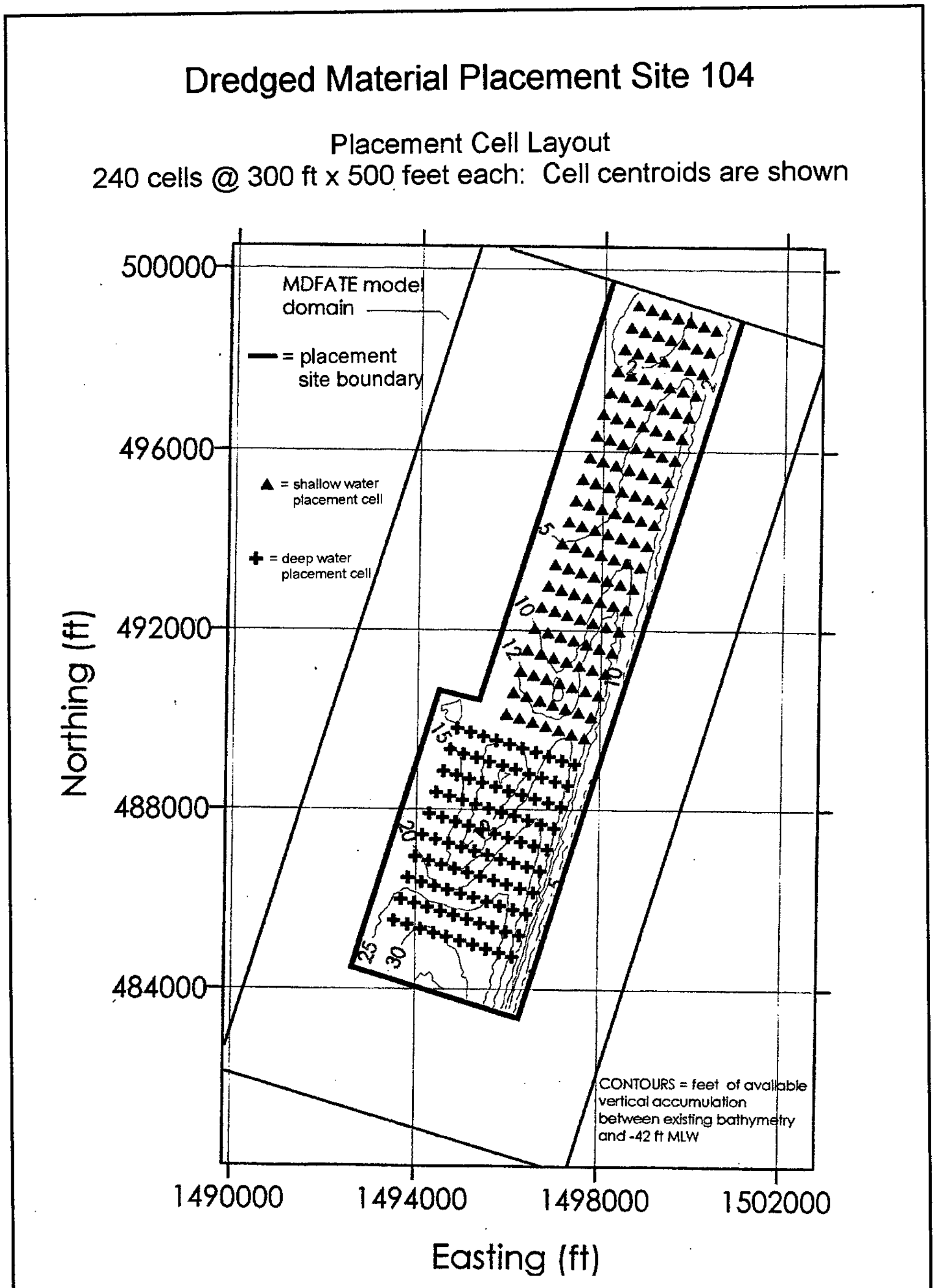


Figure 5. Placement grid

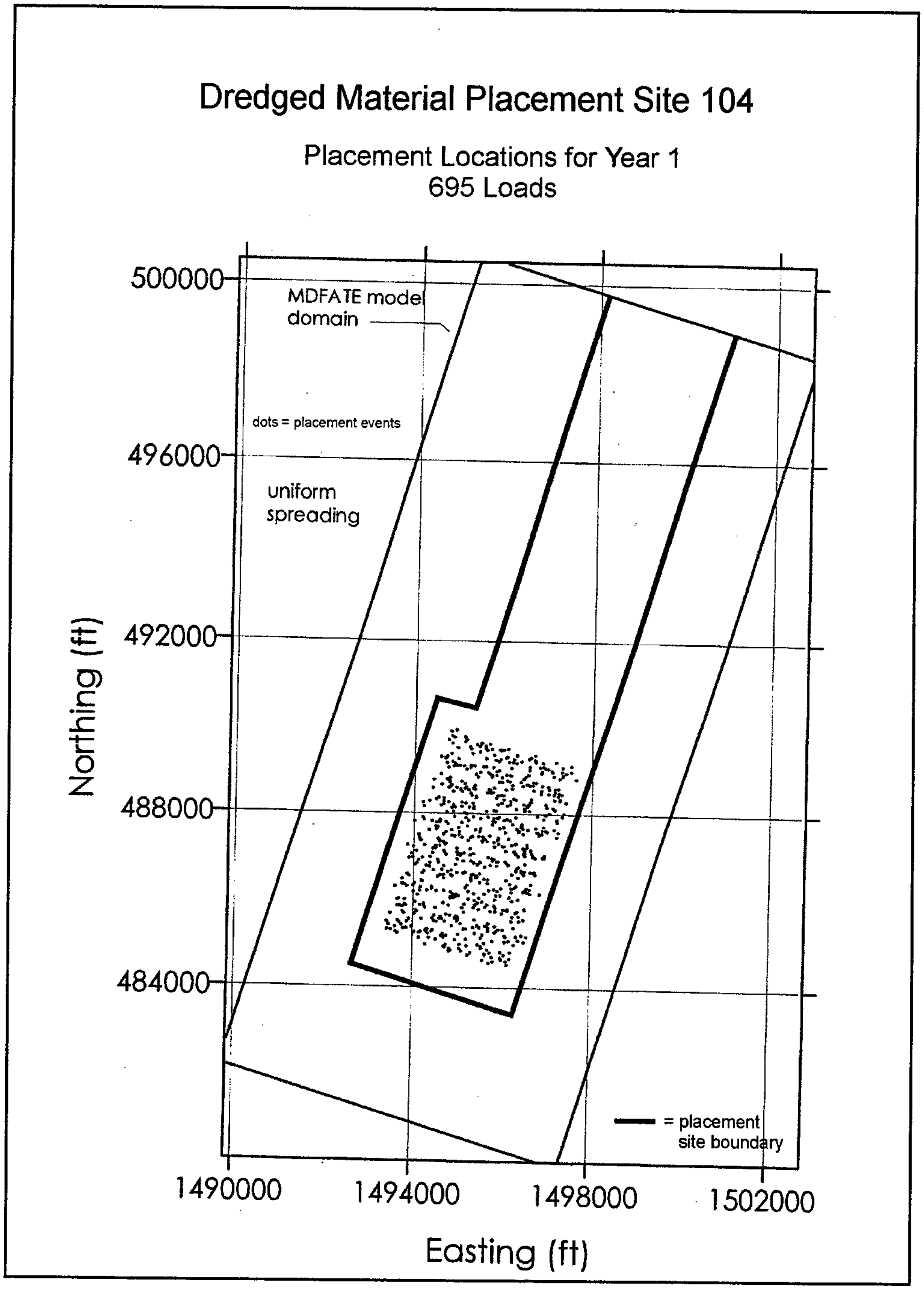


Figure 6. Location of placements for Year 1 with uniform placement

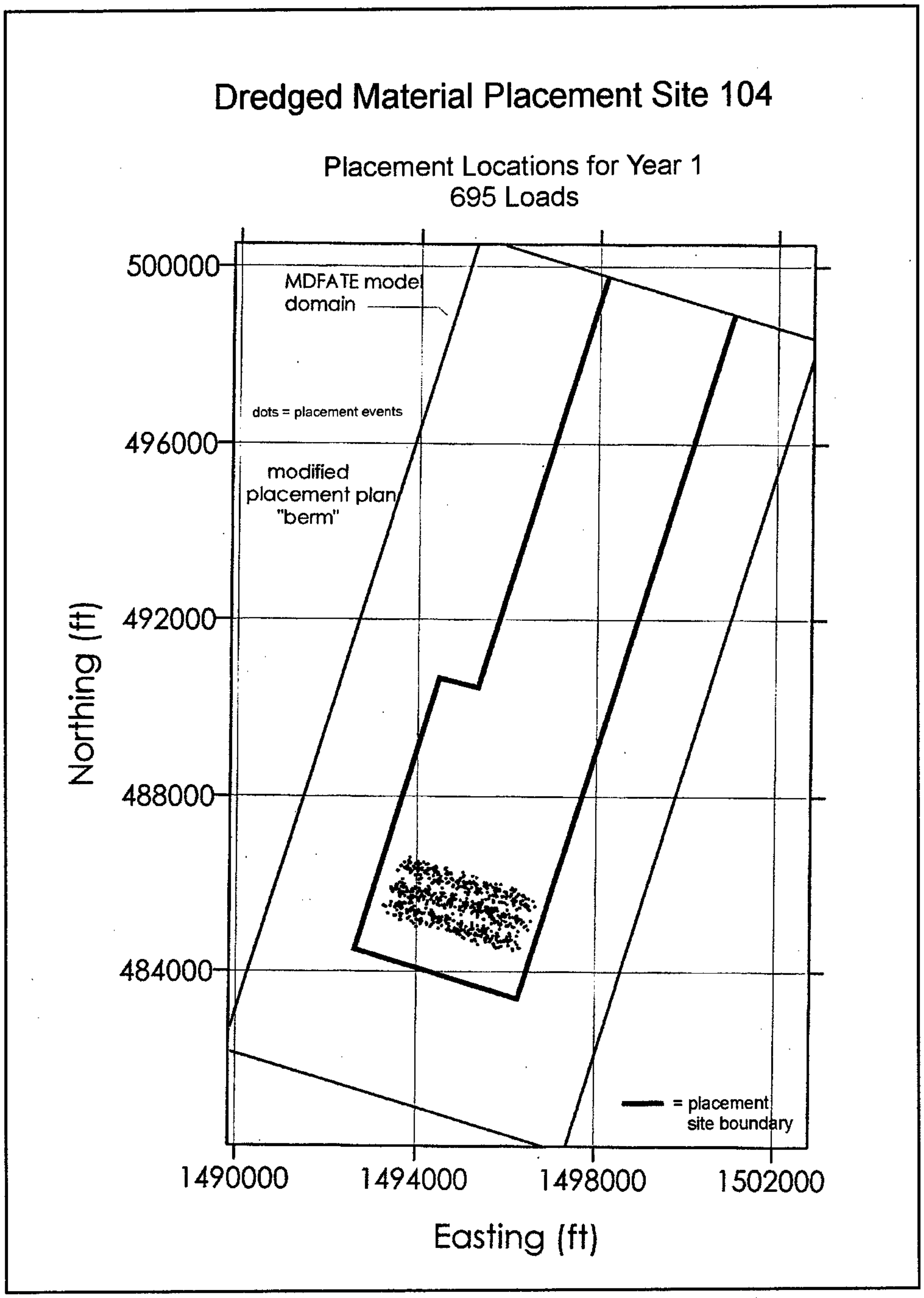


Figure 7. Locations in modified placement plan for Year 1

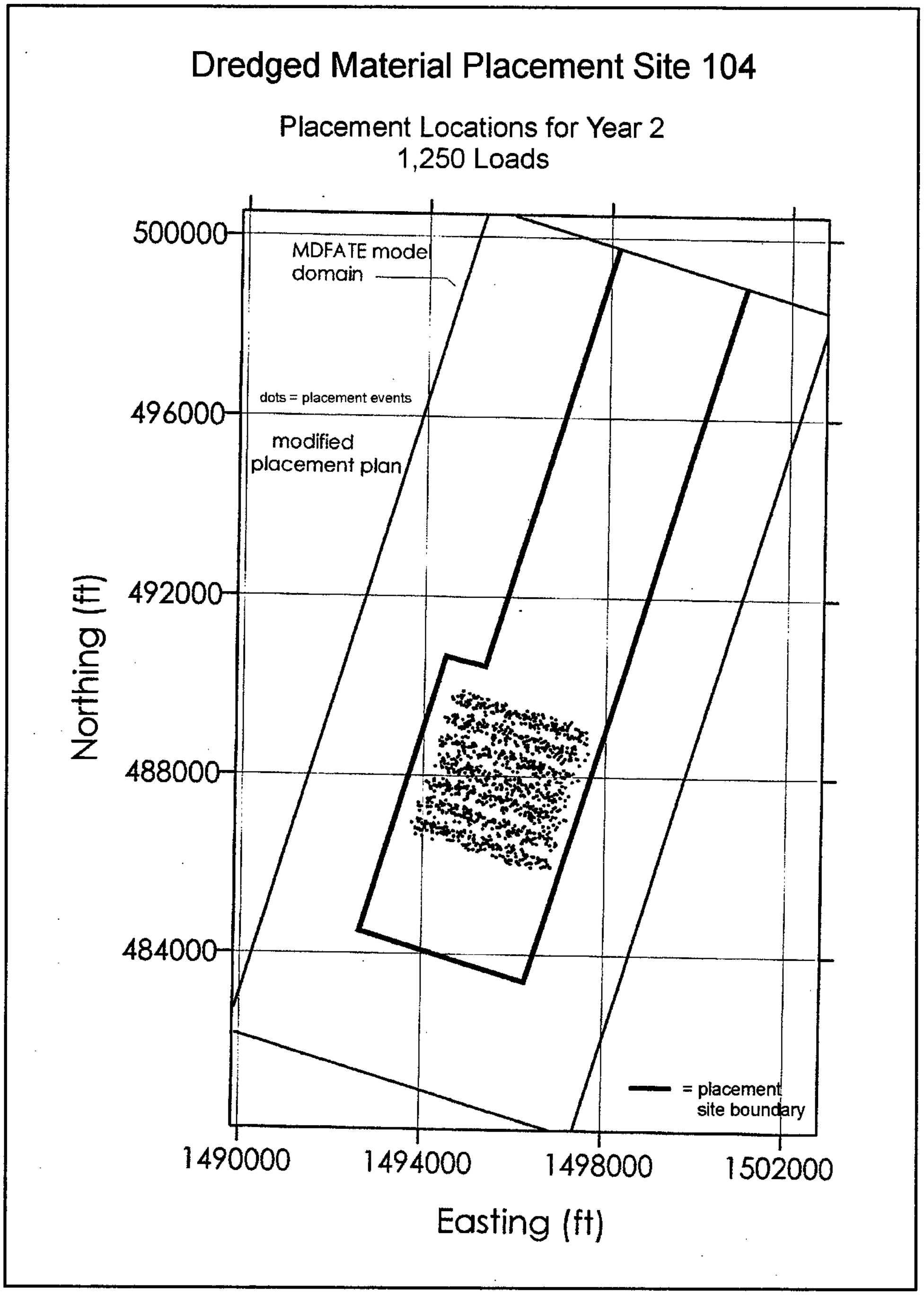


Figure 8. Locations in modified placement plan for Year 2

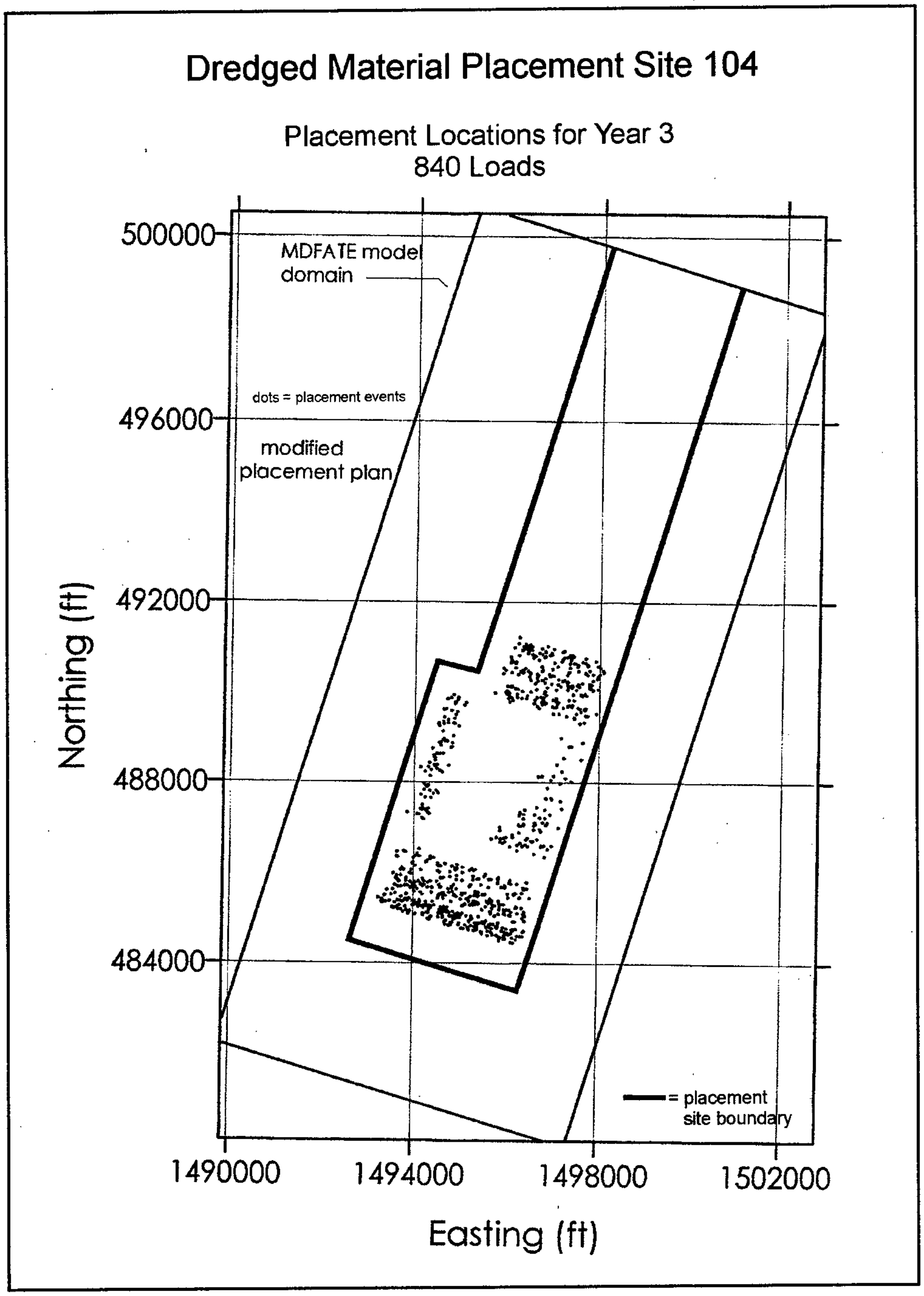


Figure 9. Locations in modified placement plan for Year 3

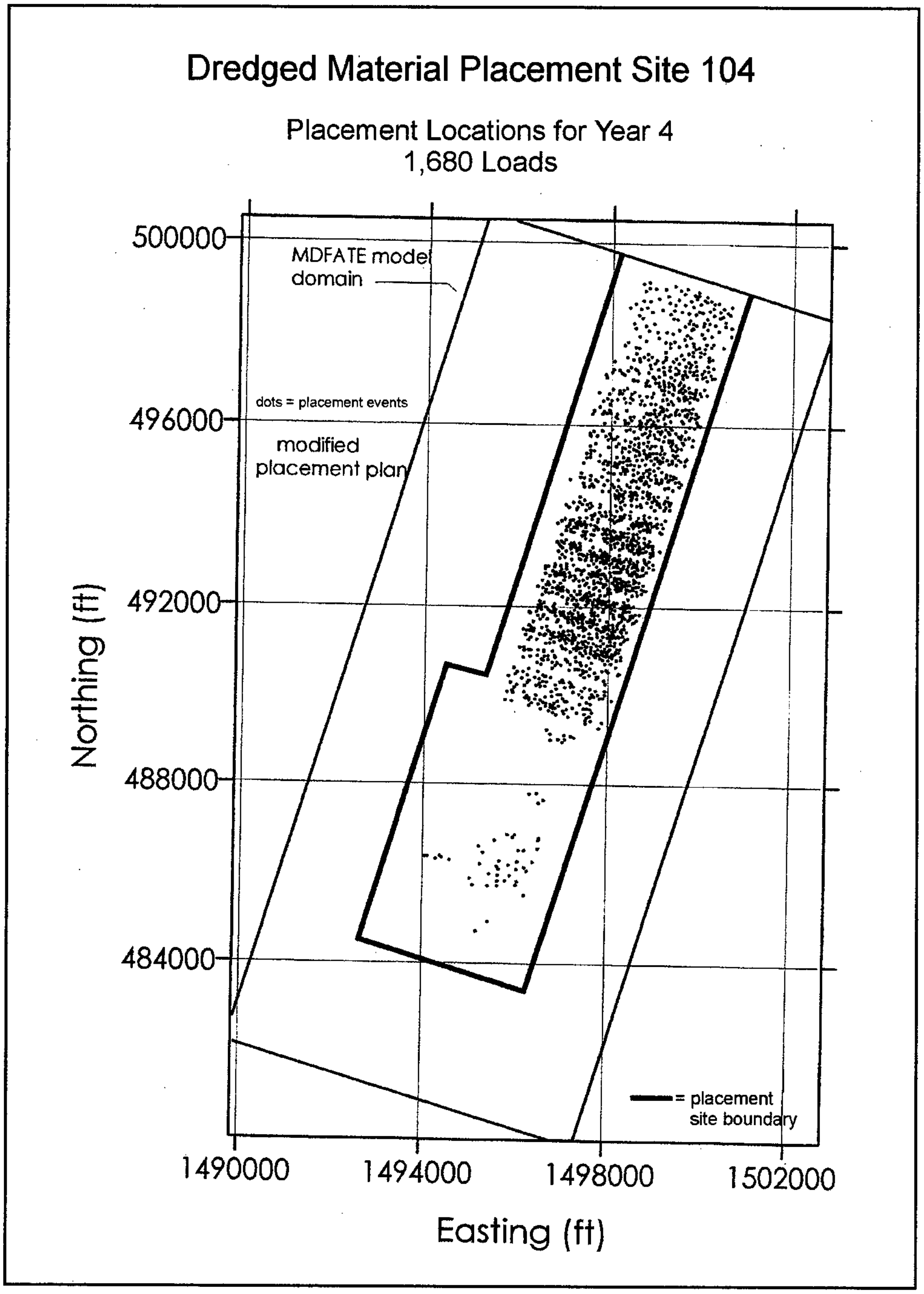


Figure 10. Locations in modified placement plan for Year 4

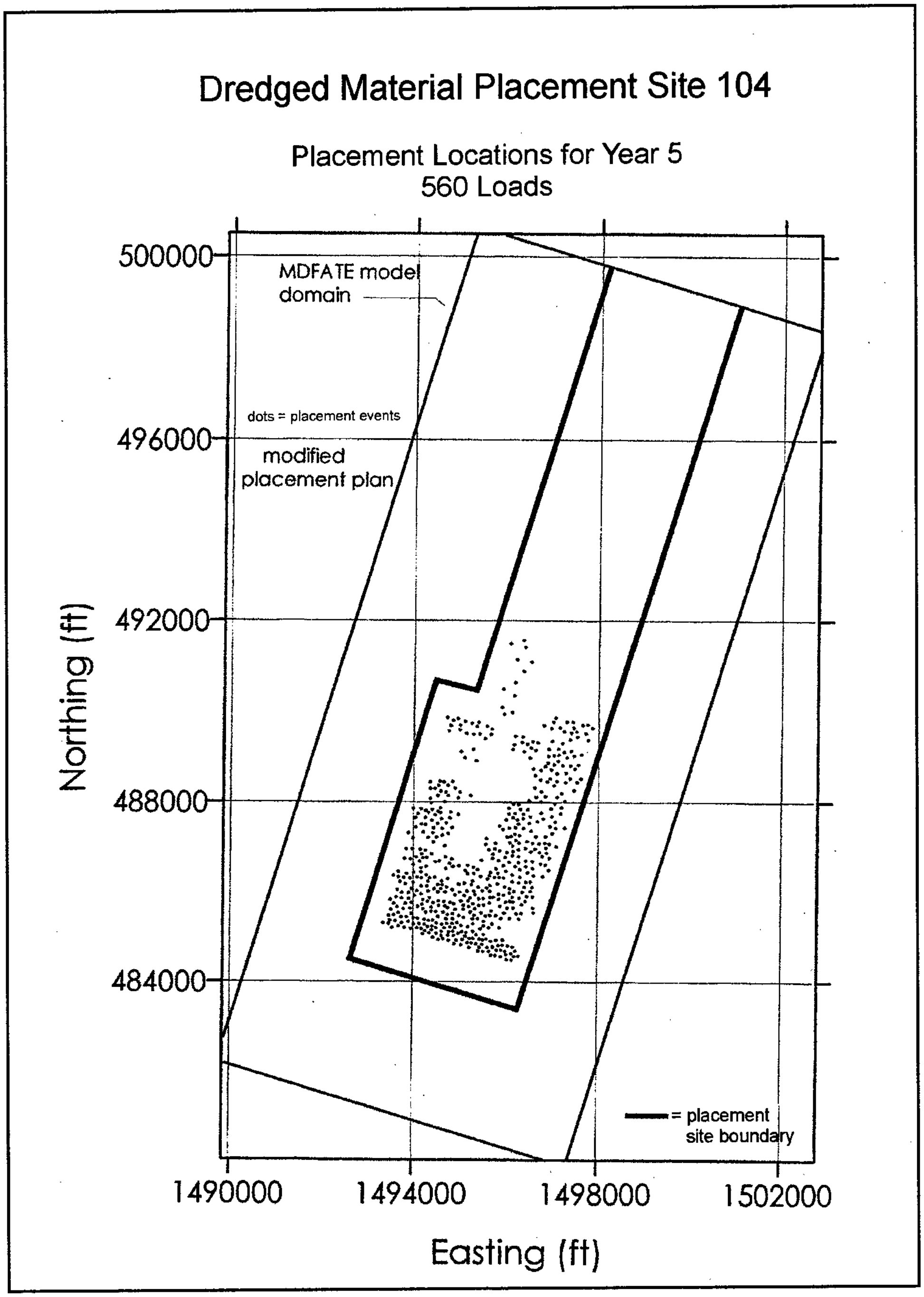


Figure 11. Locations in modified placement plan for Year 5

5 Erosion Tests

Laboratory experiments to characterize the erodibility of both inplace- and placed-dredged material were performed to support MDFATE sediment modeling for the Site 104 study. Sediment samples collected by the Maryland Geological Survey (MGS) were provided by MES. This report section describes the procedures used for the erosion tests and discusses results from those tests.

Two series of experiments were performed. The first test series (I) used sediments from a single surficial sample collected in the Swan Point Channel. The second test series (II) used a composite sediment made up from sediment cores from five upper bay channels, i.e., Craighill Angle, Cutoff Angle, Brewerton Eastern Extension, Tolchester, and Swan Point. Other proposed channels were recently dredged, and, therefore, no shoaling material was available for sampling. The composite represented over 80 percent of the channel maintenance volume proposed for placement at Site 104. Both series of experiments tested original channel sediments and slurried sediments after being allowed to settle. Results from experiments were used to estimate erosion parameters. Series I results were used in preliminary modeling, and Series II results were used in final model simulations.

Materials and Procedures

Series I

A sample from the Swan Point Channel was used in the first series of experiments. The sample was collected using a grab sampler by MGS. Site water was used in creating the sediment slurry.

Since the proposed channel maintenance materials have high water content, they will undergo mixing and dilution with ambient water during placement. Erosion experiments tested the effects of slurrying the material by a 1:3 ratio of sediment with site water after allowing the mixture to settle for different lengths of time. Slurries were poured into 11.75-cm-diam cylinders and allowed to settle 1, 3.3, and 7 days. The final settling time was based on the anticipated time for slurries to regain hydraulic shear strength under field conditions. The

intermediate times provide a time variation of the shear strength recovery. Laboratory temperature was 22 °C.

Erosion tests were also performed on the original undiluted channel sediments without addition of water. These tests were intended to characterize the end point of settling and the lowest erodibility condition for the material. Sediments were molded into erosion chambers, immediately covered with seawater, and allowed to stand for 2 days before erosion testing. Duplicate erosion tests were performed on the original sediment.

Series II

Sediment material used in the second series of experiments was a composite of six piston core sections collected by MGS from the five channels. Samples are typical of those proposed to be placed at Site 104. Core lengths roughly matched the thickness of channel deposits that would be dredged during normal channel maintenance (Table 2). Site water was also provided by MGS.

Subsamples of the upper and lower surfaces of the cores were taken, and determinations of percent moisture by weight (water weight divided by total weight) were performed. These results were checked against reported values to make sure that the cores extended only over the sediment bed thicknesses associated with maintenance dredging. Bulk wet densities (BWD) and organic content were also determined on the upper and lower surfaces of the cores.

The channel cores were first mixed individually. Two cores were taken from the Brewerton Channel Eastern Extension, each from a different location within the channel, while only one sample was taken from each of the other four. The Swan Point sample was made from the two core sections provided by MGS. The channel samples were then combined into an overall composite. The volume of each channel sample represented in the overall composite was proportional to the annual maintenance dredging from the reach as provided by the Baltimore District. These percentages are shown in Table 3.

Core descriptions and volumes mixed are presented in Table 3.

Table 2
Core Descriptions

Core	Length, cm	Channel Reach	Volume Used in Composite, cm^3	Approximate Dredging Depths, cm
1	115	Craighill Angle	2,500	100
2	150	Cutoff Angle	1,375	140
3, 4	150, 135	Brewerton Eastern Extension	2,500	150, 130
5	150	Tolchester	1,500	150
6 (a,b)	190	Swan Point	250	100

Table 3
Percent of Annual Maintenance Material from Each Channel

Craighill Entrance	11.25%
Craighill Channel	5.0%
Craighill Angle	25.0%
Craighill Upper Range	2.5%
Cutoff Angle	13.75%
Brewerton Eastern Extension Channel	25.0%
Swan Point Channel	2.5%
Tolchester Channel	15.0%

The composite represented 81.25 percent of material proposed for placement at Site 104. The remaining 18.75 percent is from the Craighill Entrance, Craighill Channel, and Craighill Upper Range. Sediment characteristics for these channel reaches reported by EA Engineering, Science, and Technology (1996) indicated larger sand fractions and lower moisture contents, resulting in less potential for erosion, than those sediments included in the composite. Thus, if sediment from those reaches had been included in the composite, the erodibility would have been slightly less than the material tested. Percent moisture by weight, BWD, and organic content were determined on the composite sediment.

The composite sediment was slurried one part sediment to three parts site water (1:3) to represent anticipated dilution shortly after placement. Slurry was added to erosion cylinders, and erosion tests were performed after 1, 2, 4, 7, and 8 days of settling. It is expected that 7-8 days would be required for the settled slurry to regain its shear strength in the field. Results for the earlier settling times provide information on the time history of the shear strength recovery. Since the erosion tests involve settling of the slurried material for different lengths of time, past experience indicates the results would not be significantly different if the slurry ratio was different, e.g., 1:2 - 1:4. Composite channel material was also tested in its original undiluted condition in triplicate to represent the lowest expected erodibility at the placement site.

Methods

Physical characterizations were performed on the samples. Sediments were stored in the Coastal and Hydraulics Laboratory (CHL) cohesive sediment laboratory cooler at 6 °C when not in use. Subsamples were taken for determining BWD and salinity of site and interstitial waters. Organic-content and particle-size-distribution determinations were also made.

BWD was determined using 25 cu cm pycnometers. Salinity was determined using an AGE Autosal instrument, with the water density determined with a PARR densitometer. Moisture content was determined as the weight of moisture lost during drying at 105 °C divided by the total sample weight. Organic content was determined as the dry weight loss on ignition after 1 hr at 550 °C. Particle-size distribution was determined on sediment samples after the removal of organics by Clorox washings and dispersion of sediments with Calgon. Additional washings with sodium carbonate/bicarbonate were made after the oxidation steps. A Coulter LS 100Q instrument was then used to determine particle size from 0.4 to 1,000 μm. This instrument uses laser near-forward scattering to estimate particle size.

Erosion experiments were carried out in a particle-entrainment simulator (PES). The PES fabricated at WES has an erosion chamber geometry identical to that used by several other investigators and is intended primarily as a field tool for erodibility assessment of undisturbed 11.75-cm-diam cohesive-sediment core sections. The PES is a portable device proposed by Tsai and Lick (1986) and used extensively for testing undisturbed core sections. An oscillating grid in the PES generates turbulence above sediment to simulate the erosive shear stress of a shear flow. Therefore, mean bed shear stress, normally used to correlate erosion, is not available as a measurable parameter. The PES must be calibrated using another erosion device to obtain this parameter. The PES was originally calibrated by comparing test suspension concentrations to those from an annular flume. The original calibration was used to correlate oscillation rate to an equivalent shear stress.

The PES test chamber is a vertical cylinder of 11.75 cm ID and was operated with 12.7 cm of Site 104 water over the sediment bed. The oscillating disk is located at a minimum distance of 5.1 cm from the sediment bed and has an excursion of 2.54 cm. The mechanical aspects of the WES PES were slightly changed and improved over the original, but the dimensions of the erosion chamber and oscillating disk were true to the original.

Equivalent shear stresses were increased stepwise during erosion tests, and the concentration of suspensions were monitored with time. PES tests started with an initial 2-min period at 100 rpm or about 0.1 Pa to suspend very loose sediment that might result from the bed preparation. The equivalent shear stresses were then stepped up to 0.2, 0.3, 0.4, and 0.5 Pa, allowing 30 min at each step.

Before each erosion test on settled slurries, the level of the sediment was measured. By ratioing the initial- and settled-sediment heights and then multiplying by the initial slurry volume concentration, the final solids volume concentration and the final BWD were calculated.

Samples of 30 ml were withdrawn for filtration. Particle-free Site 104 water was introduced during sampling to keep the water level constant in the PES erosion chamber. Samples of suspensions were analyzed to determine the mass of sediments eroded from bed surfaces. Samples were filtered through 0.45-μm

polycarbonate Nuclepore filters to determine total suspended material. Because the suspension volume of the PES is relatively small, the PES suspension concentrations were adjusted for the mass withdrawn during sampling. An adjustment equal to the calculated decrease in concentration because of the sampling and chamber replenishment was added to the results of subsequent samples.

Each shear stress step was analyzed by regression analysis to determine an erosion rate. Acceleration effects at the beginnings of the shear stress steps produce a time-varying component of erosion. To avoid this, the regression analysis was performed on adjusted concentrations from 10 to 30 min of each step.

Results from Erosion Tests

Series I

The BWDs measured on the original Swan Point sample averaged 1.1723 g/cu cm using three samples (n = 3). The moisture content, calculated from BWD, was 78 percent. This is a very low BWD for channel sediment. In Europe, a density of about 1.2 g/cu cm is used to define the limits of navigation such that sediments below this density are considered to be fluid muds possessing no appreciable shear strength. However, WES has found thick layers of sediment with similar BWDs at Calcasieu, LA, Sabine, TX, and Gulfport, MS, with laboratory tests showing that they are near a limit at which they develop important shear strength (Alexander, Teeter, and Banks 1997).

Organic content determined by loss on ignition was 9.6 percent. Mean particle size was 10.92 μm with a standard deviation of 15.1 μm. The material was 33 percent clay (less than 4 μm), 65.7 percent silt (4-74 μm), and 1.3 percent sand (greater than 74 μm). The differential particle-size distribution is shown in Plate 1.

The site and interstitial water salinity averaged 17.44 ppt, and the expected density at 22 °C was 1.01084 g/cu cm. Therefore, the original sample solids content was calculated (assuming the solids density was 2.65 g/cu cm, typical for harbor sediments) as 0.261 dry-g/cu cm. The calculated density of the 1:3 slurry was slightly lower than the measured, probably because of a small error in measuring the mix volumes. The slurry density averaged 1.0583 g/cu cm (n = 3) with the solids content being 0.0767 dry-g/cu cm.

The first PES erosion test series had three settling time periods. Densities of the settled slurry samples were 1.1333, 1.1235, and 1.1251 g/cu cm at the 1-, 3.3-, and 7-day test times. Thus, the test densities did not change as expected with settling time. The settling rate of the low-density slurry was quite high, and, possibly, subsampling errors occurred during the preparation of the cylinders, leading to variations in the initial densities and therefore in the final

densities. The final densities for the three settling periods were very similar with the slurry material settling to a density of about 1.127 g/cu cm. One should note that because the PES cylinder is only about 12 cm in diameter, these results should not be used to gauge absolute settling characteristics.

Plates 2-4 show slurry-test, time-series concentration plots and regression lines. More scatter than usual was in the concentration points. One should note that for Days 1 and 4 (3.3) settling time, the concentrations during the 0.5-Pa test step were almost constant. However, the concentration levels were extremely high (comparable with the 188 g/L solids of the settled slurry), and laboratory observations indicate that the bed had fluidized and fluffed up to the height of the sampling port.

The erosion tests performed on the original (undiluted) sediment are shown in Plates 5 and 6. Typical resuspension concentrations were about 30 times less than for the slurried and settled sediments.

The erosion rates E for the Swan Point material are plotted in Figure 12 against shear stress τ_b for each of the three settling times. The settling times in days are plotted at the data points. A linear regression line based on all data points is shown on this plot to indicate threshold shear stress value for erosion ($\tau_c = 0.0283$ Pa). Data points with regression p-values less than 0.3 were included. The indicated erosion rate constant M in Equation 1 is 1.2283 g/sq m/min.

Day 1 results were erratic. Day 3.3, if taken independently, appears to have a greater slope and possibly a lower threshold than Day 7. Given the scatter in the data, the best estimates of τ_c and M are based on the combined results.

Data were edited by deleting the highest value at 0.4 Pa (Figure 12). Regression analysis on the remaining points yielded $\tau_c = 0.0$. The result was an erosion model of the form shown below:

$$E = A\ \tau_b^{\,n} \qquad (2)$$

with $A = 33.3462$ and $n = 1$

This fit had a higher correlation coefficient ($R^2 = 0.8457$, n = 7, p-value = 0.0012) and was much better than the first fit. Figure 13 presents an erosion versus shear stress plot for the two original undiluted channel samples tested in Series I. The solid line is a regression line through all the data points. (Data points with regression p-values less than 0.3 were included.) This regression yielded a τ_c of 0.088 Pa and a M of 0.1601 g/sq m/min. The dashed line in Figure 13 is the regression line through all but the high 0.3-Pa step. That regression gives a τ_c of 0.1877 Pa and a M of 0.4433 g/sq m/min and has a much higher correlation coefficient ($R^2 = 0.747$, n = 6, p-value = 0.0264) than the first regression.

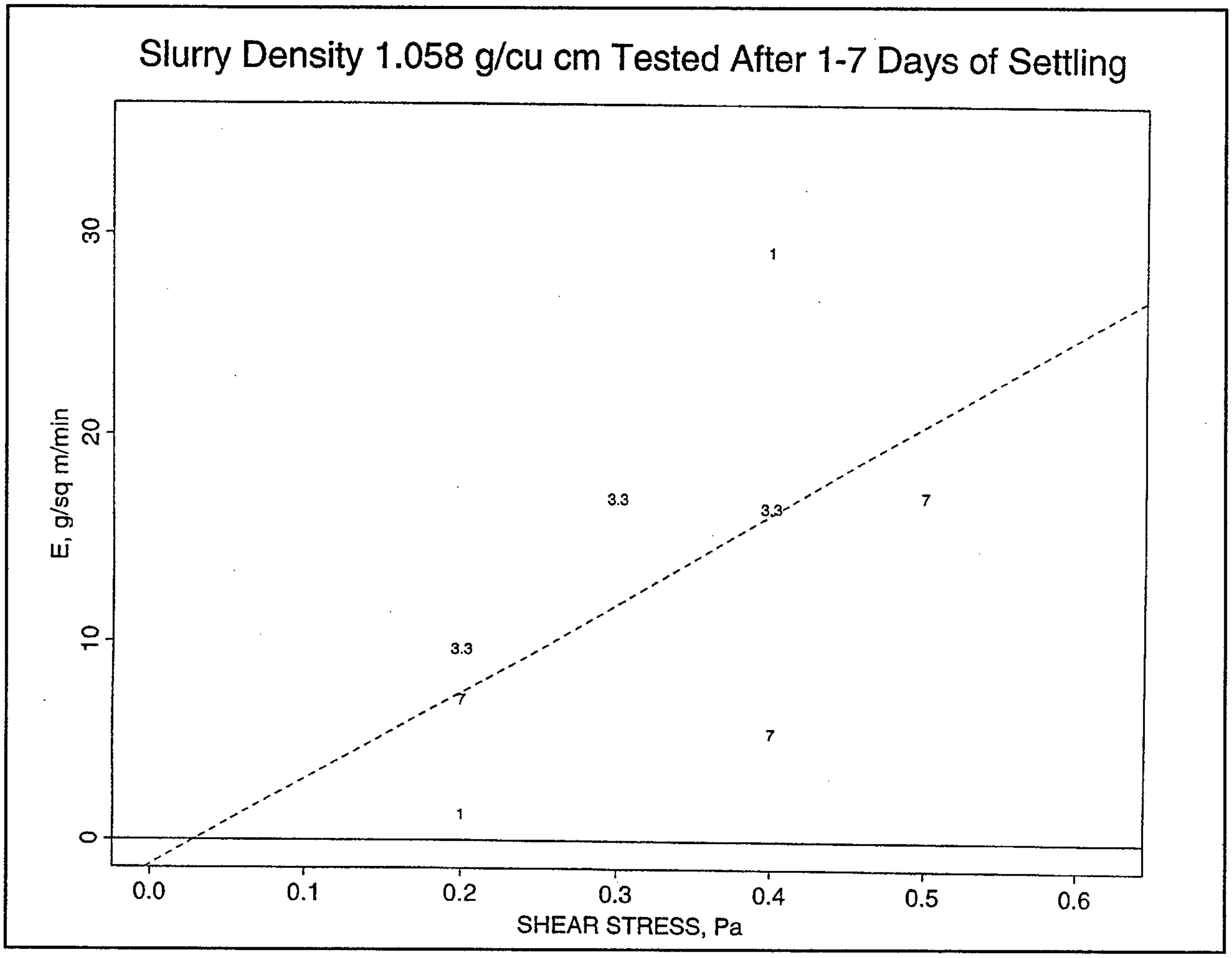


Figure 12. Erosion rate versus shear stress for Swan Point settled slurries (numbers on plot indicate settling days)

Series II

Results of the core characterizations are presented in Table 4. The first number is for the top of the core, and the second number is for the bottom section. The samples were used as they were sent to WES, i.e., they were not cut.

The average surface density of these cores is 1.149 g/cu cm (95 percent CI: 1.129-1.169 g/cu cm), which is much lower than the bottom density that averaged 1.309 g/cu cm (95 percent CI: 1.276-1.343 g/cu cm). Results for the composite are 1.251 g/cu cm BWD, 67.44 percent moisture, and 10.1 percent organics.

As indicated in Table 5, results for the core-sample particle-size (in micrometers) analysis were all very similar.

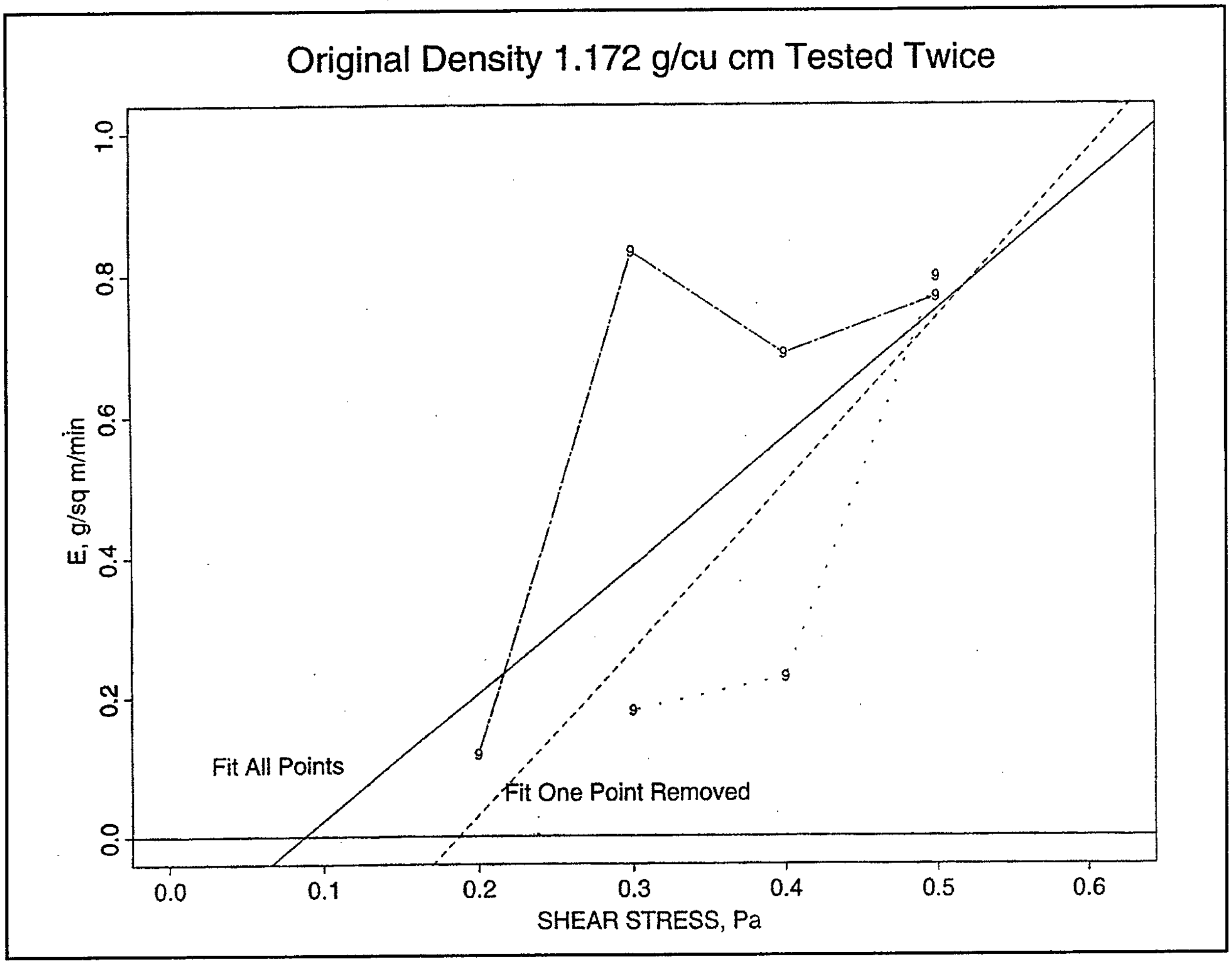


Figure 13. Erosion rate versus shear stress for Swan Point channel sediment (numbers on plot indicate mean volume concentration)

Table 4
Sediment-Core Characterization (top/bottom)

Core	Channel Reach	BWD, g/cu cm	Moisture percent	Organics percent
1	Craighill Angle	1.134/1.326	79.6/57.2	10.7/8.6
2	Cutoff Angle	1.133/1.299	80.0/61.5	10.9/10.1
3	Brewerton Extension	1.178/1.348	74.6/58.3	10.7/10.0
4	Brewerton Extension	1.165/1.323	77.4/60.8	10.6/10.4
5	Tolchester	1.150/1.304	78.1/59.7	10.3/10.1
6	Swan Point	1.133/1.255	81.0/66.2	10.6/10.2

Table 5
Sediment-Core Particle Size, μm

Core	Channel Reach	Mean	Median	Std Dev
1	Craighill Angle	10.05	5.75	13.1
2	Cutoff Angle	10.36	5.61	14.2
3,4	Brewerton Extension	12.45	7.12	15.5
5	Tolchester	11.25	6.56	13.9
6	Swan Point	11.1	6.12	14.4
Composite		10.88	6.02	14.2

Differential particle-size distributions are presented in Plates 7- 20.

Plates 21-25 show experimental suspended-sediment concentrations and the regression for each erosion step. Erosion rates are plotted against shear stresses in Figure 14. Plates 26-28 show experimental results for tests on the original composite material without addition of water. Erosion rate versus shear stress are plotted in Figure 15.

There was a more systematic change in erosion threshold and erosion rate constant with settling time than in the Series I tests. For example, τ_c's are plotted against settling time in Figure 16. The area under the age curve from 0 through 7 days was determined and divided by 7 to obtain an average value. This averaging technique was slightly more conservative than a simple average and yielded an erosion threshold τ_c of 0.219 Pa or 0.00456 lb/sq ft. The average value of the erosion rate constant M is 11.9 g/sq m/min or 0.1466 lb/sq ft/hr.

The original composite of bulk channel material, without addition of water, was also tested. Shear stresses of up to 0.6 Pa were applied in these tests. Unfortunately, the threshold for erosion was not reached. Figure 15 shows only statistically significant erosion values versus shear stress. The slope of the regression line shown in Figure 15 is not statistically different from zero. Erosion values were very low and uncorrelated to shear stress. In the absence of experimental information, the only recourse was to estimate the erosion parameters. An assumed τ_c = 0.7 Pa or 0.0146 lb/sq ft and M = 50 g/sq m/min or 0.615 lb/sq ft/hr appear to be reasonable and are consistent with experimental findings.

Discussion on Using Erosion Test Results in Sediment Models

Series I

Other sediment data indicate that most sediments proposed for placement at Site 104 would have lower moisture content and erodibility than the surficial

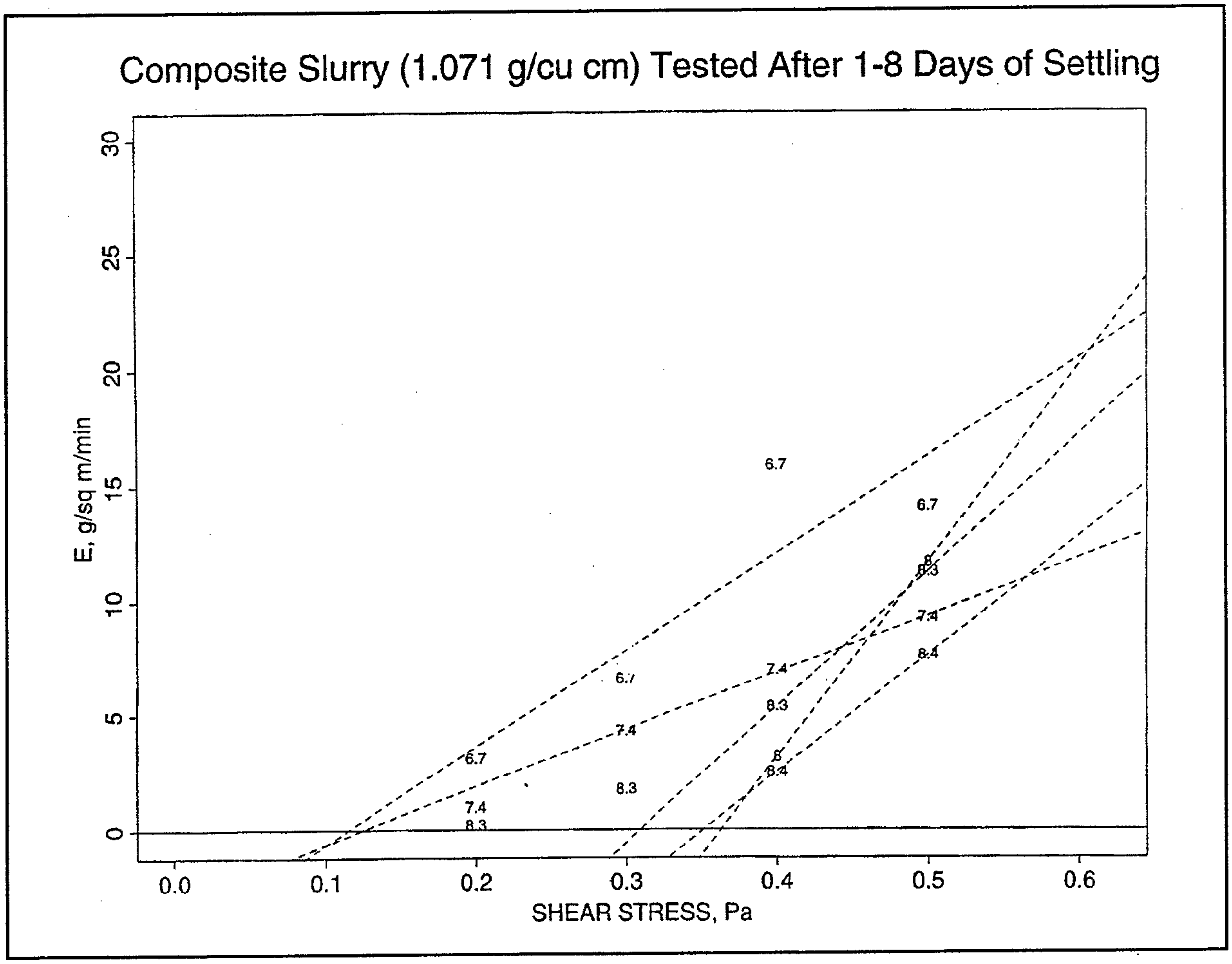


Figure 14. Erosion rate versus shear stress for composite settled slurries (numbers on plot indicate mean volume concentration at time of test)

Swan Point sample tested in Series I experiments. Therefore, the Swan Point results were used in conjunction with other erosion information to produce the final Series I results. Series I results were used only in preliminary modeling until the Series II results were available. EA (1996) collected 26 surficial samples in Chesapeake Bay approach channels to Baltimore Harbor. Average water content for these surficial samples are given in Table 6.

The water content (by weight) of the Swan Point Channel surface grab sample taken by MGS for this study was 78 percent, which was higher than all other channel reaches noted above. Since erodibility of cohesive sediments is highly dependent on the water content and related parameters such as density, it is safe to assume that the Swan Point sediment tested had higher erodibility than surficial sediment from other channel reaches. Therefore, sediments of lower water content from locations outside Chesapeake Bay were considered in the preliminary evaluation of erosion losses from Site 104 since no erosion results were available for lower water content sediments in the upper bay channels during the Series I tests.

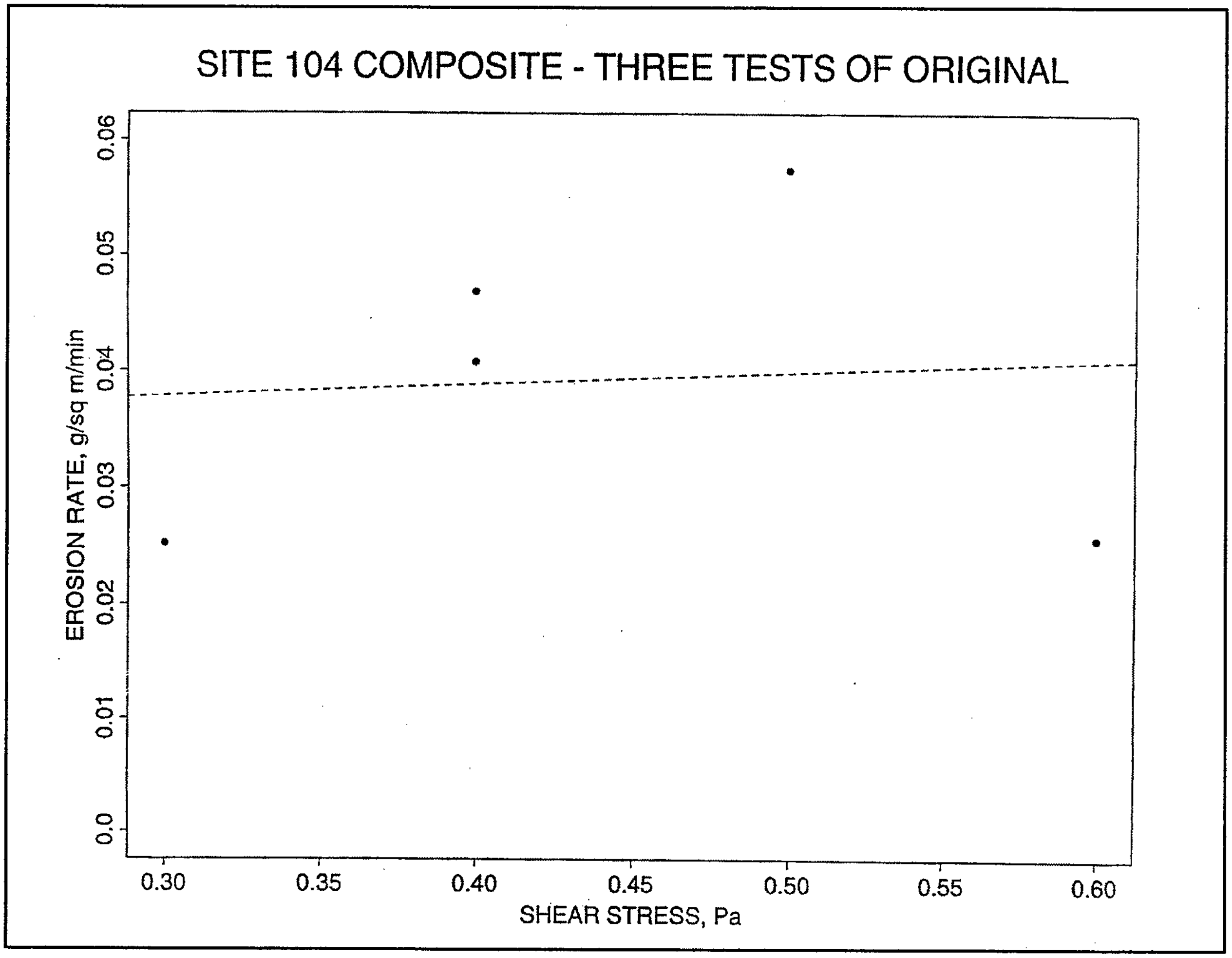


Figure 15. Erosion rate versus shear stress for composite channel sediment

For preliminary MDFATE simulations that approximately represent material that will be placed at Site 104, a set of erodibility factors was developed for the four sediment types of 53, 60, 71, and 75 percent water identified from Table 6. These factors were determined by using erosion test results from Swan Point and results from New York Harbor low-water-content sediments. The New York Harbor composite sediment had 7.2 percent organic material, a BWD of 1.375 g/cu cm, and 28 percent clay content. The New York Harbor composite was tested over a range of slurry densities and is likely to have similar erodibility parameters as the low-water-content sediments in the upper bay channels.

Water content fraction W (water weight divided by total weight) is related to solids volume concentration Cv by:

$$Cv = (1 - W) / (W(\rho_s - \rho_\ell) + 1) \tag{3}$$

and BWD is related to Cv by

$$\mathrm{BWD} = Cv(\rho_s - \rho_\ell) + \rho_\ell \tag{4}$$

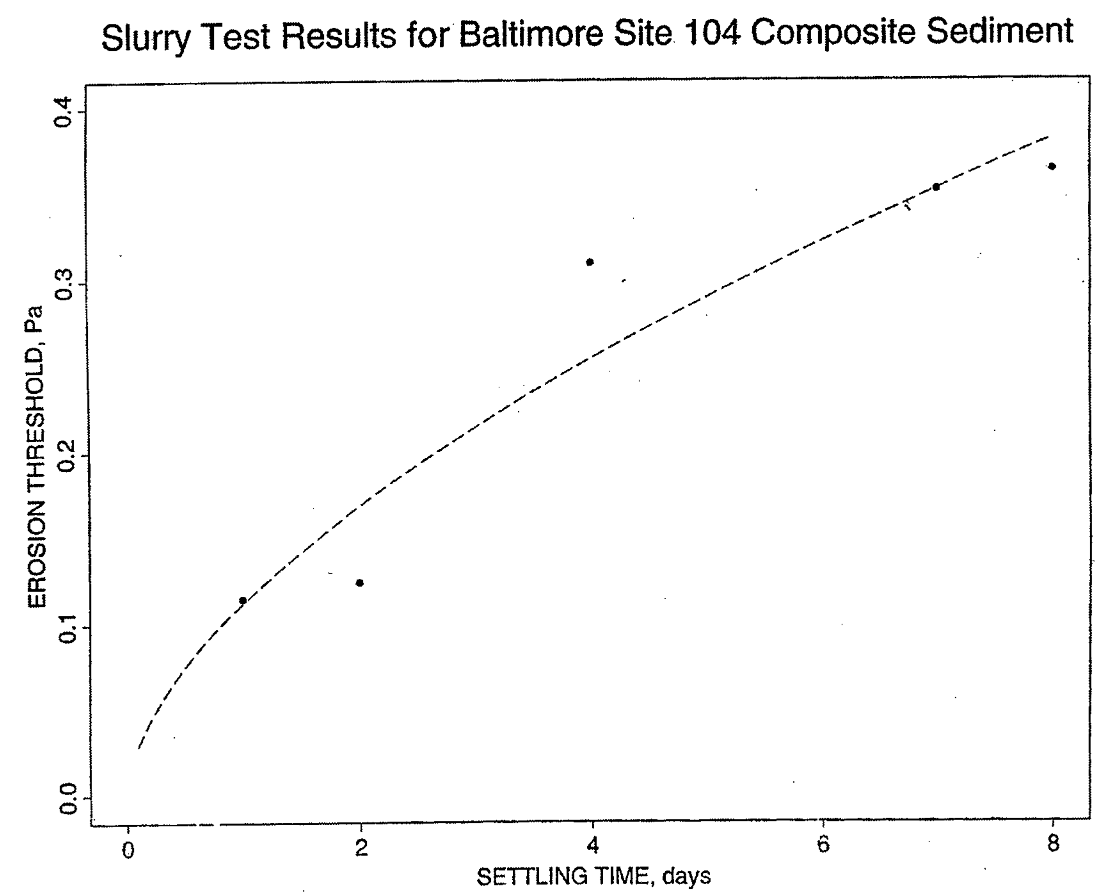


Figure 16. Erosion threshold versus settling time for composite slurries

Table 6
Water Content of Sediment Samples by Channel Reach

Reach	Percent Water	Number of Samples
Craighill	51.9	4
Craighill Entrance	54.1	3
Craighill Upper	60	3
Tolchester	60.5	4
Brewerton Eastern Extension	67.8	4
Craighill Angle	72.2	2
Cutoff Angle	73.2	3
Swan Point	75.1	3
Average by Reach	64.4	8
Average by Sample	63.5	26

where ρ_s and ρ_ℓ are the solids and liquid density. For the site water provided by MES, ρ_ℓ was 1.01084 g/cu cm at room temperature, and ρ_s was assumed to be 2.65 g/cu cm, which is a typical value for harbor sediments. Porosity is 1 - *Cv*, and voids ratio is 1/*Cv* - 1. (Based on laboratory work, initial Swan Point deposits will have a voids ratio as high as 15.)

A relationship between *Cv* and critical shear stress for erosion τ_c was developed using the Swan Point erosion test which, as previously noted, slurried the sediments by a 1:3 ratio and allowed them to settle for 1-7 days. New York Harbor composite tests were slurried to *Cv* = 0.0644, 0.0908, and 0.1244 and allowed to settle over similar times. Figure 17 shows a plot of the nonlinear relationship:

$$\tau_c = 13.9553\, Cv^{\,0.0112247} - 13.38314 \qquad (5)$$

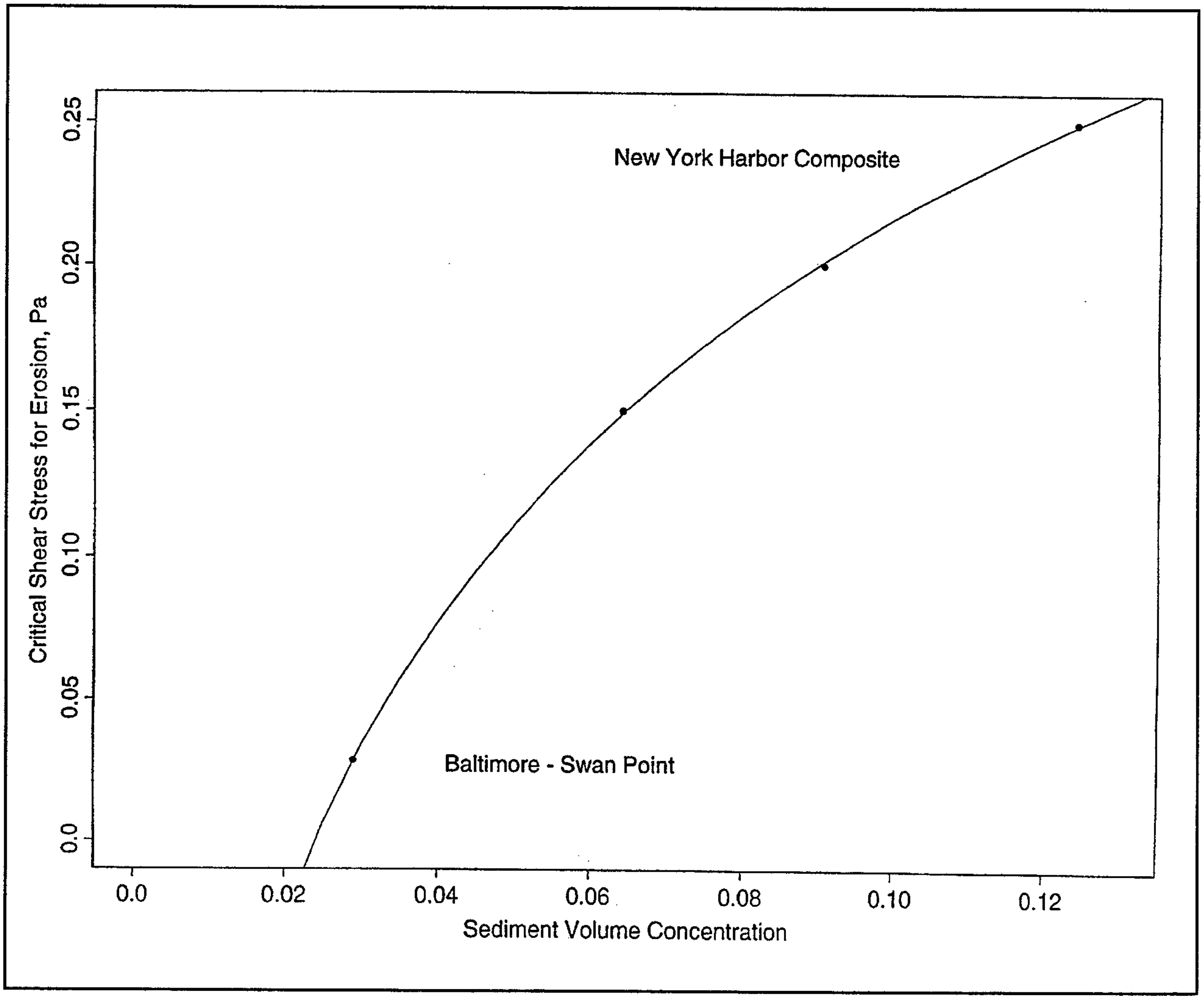


Figure 17. τ_c versus volume concentration for Swan Point and New York Harbor sediments

This curve appears to be reasonable, as sediments must have some finite *Cv* to develop a yield stress and a finite τ_c. The water contents by weight *W*, volume concentration *Cv*, and erodibility parameters τ_c and *M* for the four sediment types are given in Table 7.

Table 7
Characteristics of Swan Point and New York Harbor Sediments

Type	Dredging cu yd/year	*W*	*Cv*	τ_c lb/sq ft	*M* lb/sq ft/hr
1	325,000	0.53	0.224	0.0027	0.0931
2	350,000	0.6	0.203	0.0023	0.0786
3	1,000,000	0.71	0.135	0.0011	0.0308
4	325,000	0.75	0.113	0.0005	0.0141

Weighting of the above four sediment types into one representative for erodibility considerations is difficult because of the nonlinearity of erosion. Accumulating mass of solids using an average weighted by the expected volumes of deposited material would be appropriate. However, with respect to erodibility, this may not be the case. Since only one sediment type can be used in the MDFATE simulations, that one sediment type must erode as the aggregate of the four sediment types listed above. Eroded amounts are nonlinearly related to *W* over ranges of shear stress. For example, if two hypothetical sediment types were disposed in equal quantities, and if one type eroded 0 percent and the other 25 percent, the appropriate single-sediment representation would erode 12.5 percent. Because of the nonlinearity in erosion characteristics, this would not be ensured by simply averaging the water contents of the two types.

Appropriate weightings were developed, given the available information, by including both dredging quantities and expected erosion rates. This was done by integrating erosion quantities weighted by expected dredging volumes for the four material types over the frequency-distribution curve of shear stresses computed by CH3D for the first 200 days in 1993. The integration of erosion yielded annual quantities for each material type assuming a constant footprint size. A water content weighted by these expected erosion quantities is equal to 64.8 percent (versus 66.8 percent for a dredging-volume weighted average). Using the previously developed relationships, $\tau_c = 0.086$ Pa (0.001798 lb/sq ft) and $M =$ 4.58 g/sq m/min (0.0563 lb/sq ft/hr) for material with $W = 0.648$. These values of τ_c and *M* were employed in preliminary MDFATE simulations for freshly deposited material (less than 1 week old).

The EA (1996) sediment-sampling report includes some surface samples taken east of Site 104. Sample KI2 in particular was collected from about 40-ft water depth and is representative of the site. Moisture content of that sample was 67.8 percent. E2SI (Project 97-190) collected borings and MGS collected piston cores from Site 104. Surficial samples P-1, P-2, P-3, P-9, and B-2/S-1

averaged 68 percent water by weight (n = 5, standard deviation of 10.1). Based on these samples, a surficial water content of 68 percent was assumed.

Using the results of erosion tests on surficial Swan Point sediments at in situ density, an erosion threshold τ_c of 0.188 Pa and an erosion rate constant M of 0.4433 g/sq m/min were obtained after dropping one spurious point as reported earlier. The water content of this material was 78 percent, with a bulk wet density of 1.173 g/cu cm and a solids volume concentration of 0.099.

Channel material from New York Harbor tested at in situ density had a density of 1.363 g/cu cm and a solids volume concentration of 0.214. The τ_c for this material was found to be 0.37 Pa. At a shear stress of 0.5 Pa, Swan Point and New York Harbor sediments eroded similarly, e.g., 0.75 and 0.6 g/sq m/min, respectively. An erosion rate reference constant Mr was therefore taken as 0.7 g/sq m/min. Using the same method applied to slurried material earlier to interpolate between these two sediments, the equation $\tau_c = 1.5826\, Cv + 0.03132$ was determined. The τ_c for fully settled material at Site 104 was calculated as 0.2782 Pa (0.00581 lb/sq ft), with M being 0.878 g/sq m/min (0.01080 lb/sq ft/hr). These values for τ_c and M were used in preliminary MDFATE simulations for material more than 1 week old.

In summary, erosion results from New York Harbor material tests were combined with those from the Swan Point material tests to yield an approximation of the erosion of material that might be placed at Site 104. Comparing the erosion potential determined from those calculations with the Series II results below, the composite formed from actual upper bay channel sediments can be seen to be less erodible.

Series II

The erosion parameters developed from the Series I experiments were employed in preliminary MDFATE computations before results from the more realistic Series II experiments were available. These early simulations aided in developing the linkage between MDFATE and CH3D and in developing the final placement plan. After results from the Series II experiments became available, they were applied directly. MDFATE results to be presented later utilized the erosion parameters from the Series II experiments: an erosion threshold τ_c of 0.219 Pa or 0.00456 lb/sq ft and M of 11.9 g/sq m/min or 0.1466 lb/sq ft/hr for mound material up to 7 days after placement, and τ_c of 0.7 Pa or 0.0146 lb/sq ft and M of 50 g/sq m/min or 0.615 lb/sq ft/hr for mound material in place for longer than 7 days.

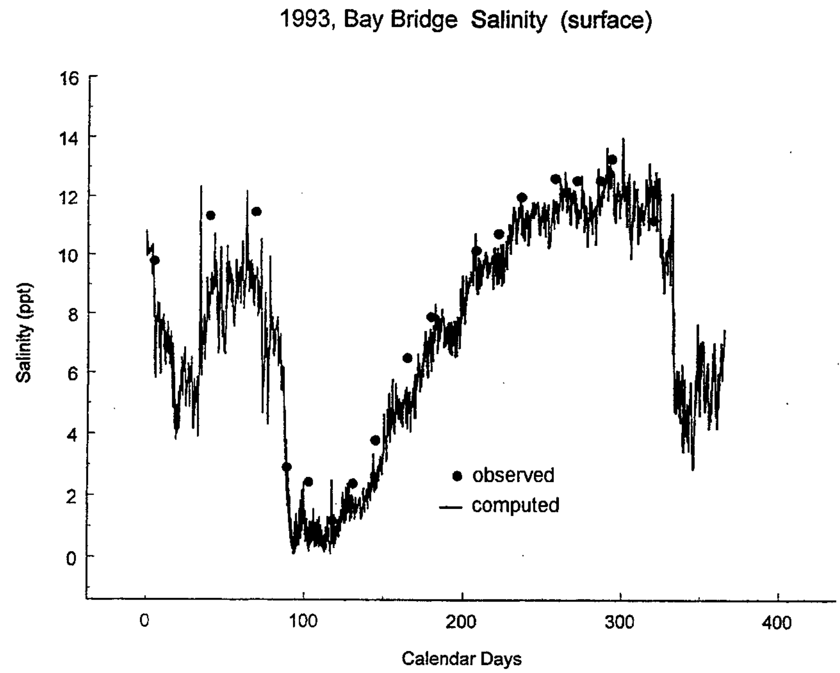
6 Hydrodynamic Simulations

As previously discussed, a CH3D-WES model of the upper bay was developed and applied to provide water-surface elevation, depth-averaged current, and bottom shear-stress data to MDFATE. The shear stresses control the rate at which material is eroded, while the depth-averaged currents impact transport results from the short-term fate computations in MDFATE. For each 3-hr time-step in the five 1-year MDFATE simulations, the CH3D-WES results were "mapped" onto the entire MDFATE model domain using a multipoint interpolation scheme. Both CH3D-WES model verification and production runs utilized 1993 forcings. These forcings consisted of freshwater inflows from tributaries such as the Susquehanna River, wind forcing from the Baltimore - Washington International Airport, surface heat exchange determined from meteorological data, and water-surface elevations and salinity at the southern boundary of the grid shown in Figure 3.

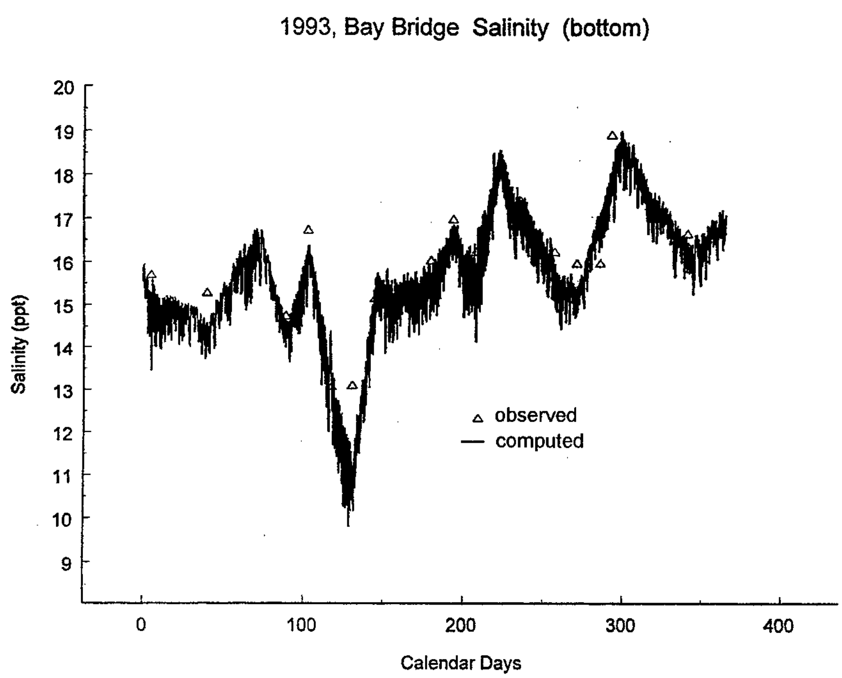
Figure 18 shows a comparison of computed and observed near-surface and near-bottom salinities at the Bay Bridge for a portion of 1993. One can see that the model computes the impact of the large spring runoff from the Susquehanna River (Figure 19) quite well and maintains the large stratification that drives baroclinic currents. The reason for model results appearing slightly too "fresh" is probably because the model is not diverting enough fresh water through the Chesapeake and Delaware (C&D) Canal during the high Susquehanna River flows. The C&D flow was set to be a constant 785 cfs directed toward the Delaware River. This is considered to be the long-term average flow through the canal.[1]

Demonstrating that the hydrodynamic model accurately reproduces currents over Site 104 was considered important. However, no field data existed for the simulation period. Thus, the reproduction of currents over the site can only be inferred from an inspection of data collected at other times. During July 1997, Dr. Larry Sanford of the University of Maryland Horn Point Laboratory collected Acoustic Doppler Current Profiler (ADCP) data over about one tidal cycle along a transect starting just above the Bay Bridge and extending northward along the middle of the site. These data generally showed that

[1] Personal Communication, 1998, W. Boicourt, University of Maryland Center for Environmental Studies (UMCES-HPL), Horn Point Laboratory, Cambridge, MD.



a. near surface



b. near bottom

Figure 18. Comparison of computed and observed salinity at Bay Bridge in 1993

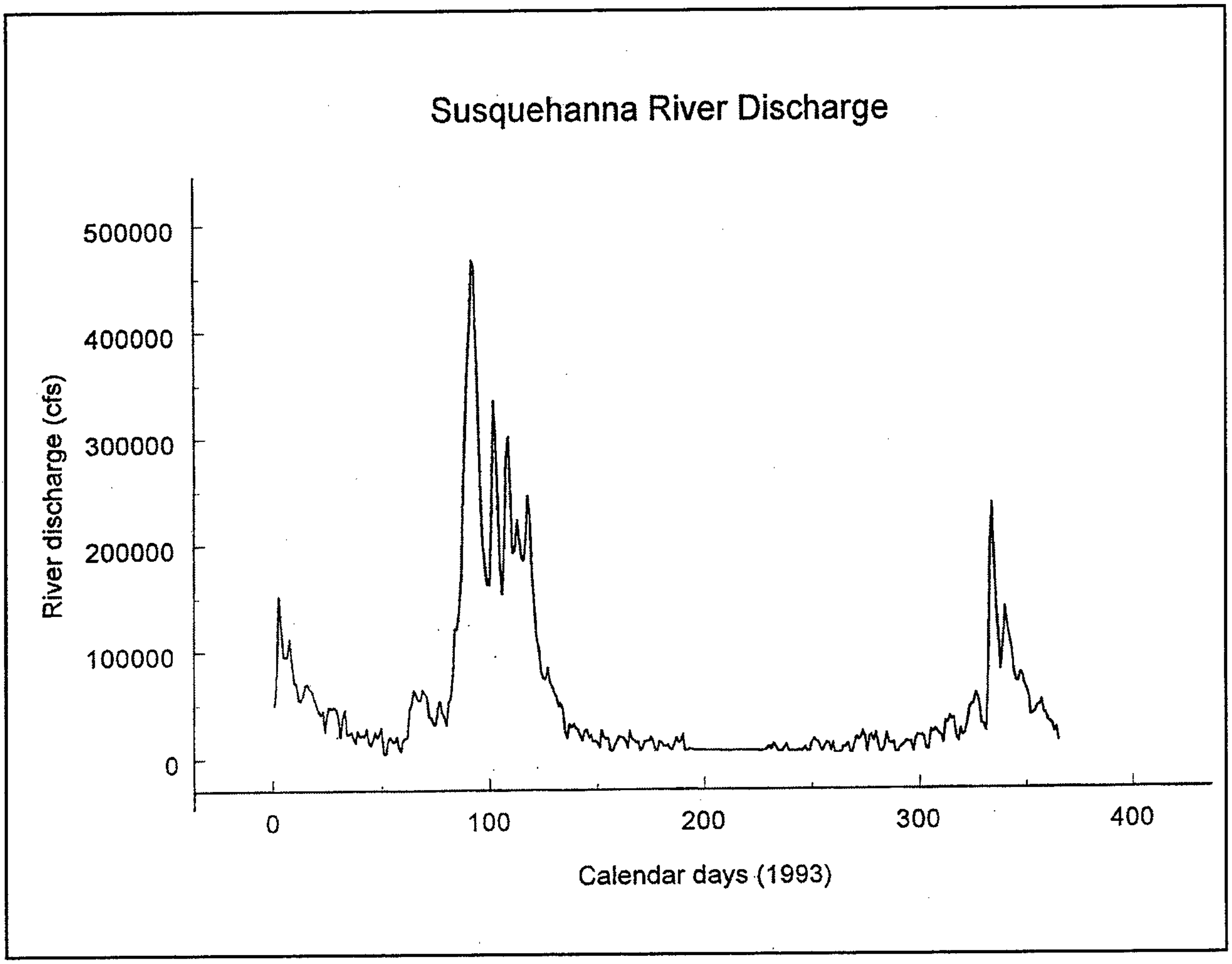


Figure 19. Freshwater inflow on Susquehanna River during 1993

maximum flood currents near the surface were in excess of 1.0 fps with maximum ebb currents being in excess of 2.0 fps. Currents near the bottom during maximum flood and ebb were in the 0.5- to 1.0-fps range (Figures 20-21). As illustrated in the predicted tidal current plot shown in Figure 22, the tide at the site is mixed. Thus, values of maximum flood and ebb currents vary. Figure 22 was generated using a program called "Tides and Currents," which is based on the National Ocean Service tidal prediction equations.[1] Prototype data collected near the Chesapeake Bay Bridge by Hamilton and Boicourt (1984) are presented in Figure 23 for near-surface (depth = 2.4 m (7.9 ft)) and near-bottom (depth = 16.8 m (55.1 ft)) currents.

Figures 24-25 show CH3D-WES simulated current results for July 1993 at a location in the southern part of Site 104 (depth = 65 ft) and a location near the middle of Site 104 (depth = 50 ft). Comparing the available prototype data with Figures 24-25, one can see that the CH3D-WES model results agree with

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[1] Personal Communication, 1997, L. Sanford, University of Maryland Center for Environmental Studies, Horn Point Laboratory, Cambridge, MD.

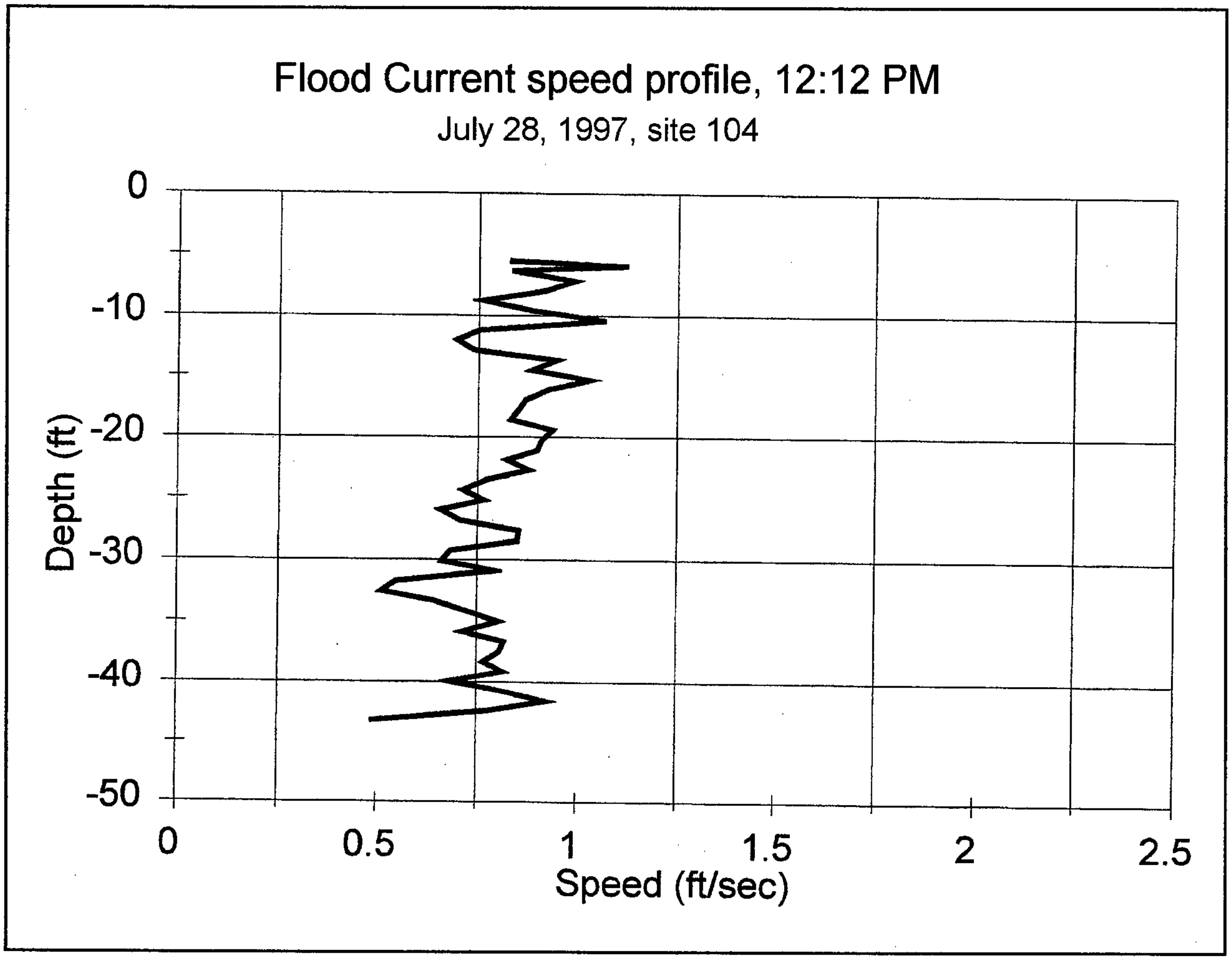


Figure 20. UMCES-HPL ADCP data near maximum flood

the prototype data as far as relative magnitude of the near-surface and near-bottom currents. The above results lend credibility to the simulated current and bottom shear stresses generated by the CH3D-WES hydrodynamic model for input to MDFATE. Given the vertical structure illustrated in Figures 24-25, bottom shear stresses computed from a 3-D hydrodynamic model will be significantly different from those computed using vertically averaged currents.

With the CH3D-WES model considered to be adequately reproducing water column stratification and currents over Site 104, a year-long simulation with existing bathymetry at Site 104 (Figure 4) was made. Since the placement period will be initiated on 1 November of each year, the final bottom shear-stress file reflects hydrodynamics that start on 1 November and run until 1 November of the next year. Figures 27-31 show the computed bottom shear stresses at three locations in the site (Figure 26) for each of the 5 years of placement. For each placement year, bottom shear stress is shown for a 140-day duration beginning on November 1. Although the forcings are the same for each year of hydrodynamics, the Site 104 bathymetry at the beginning of each year reflects the buildup on the bottom of material contained within the site from the previous

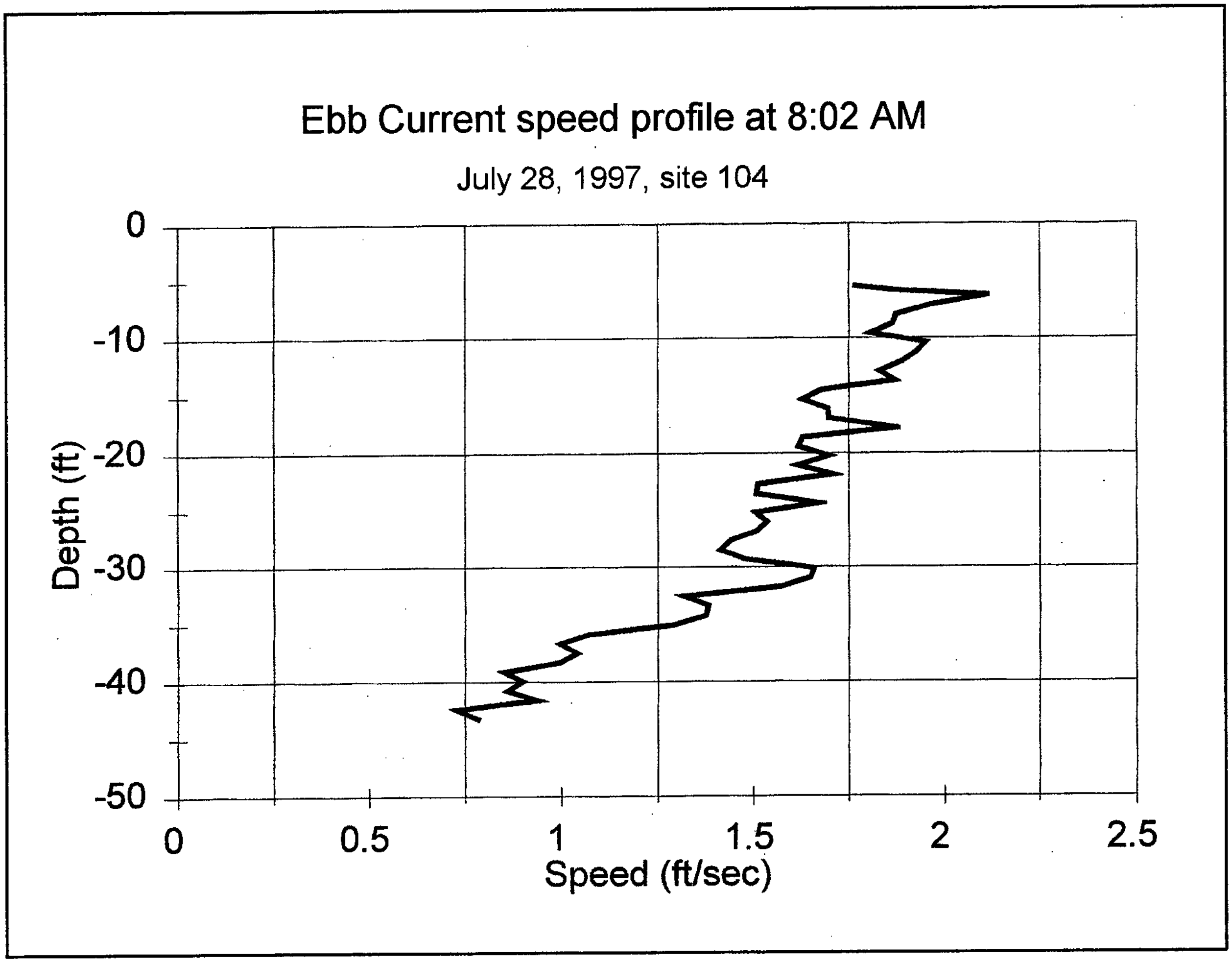


Figure 21. UMCES-HPL ADCP data near maximum ebb

year's placement. Thus, Figures 27-31 show bottom shear stress at locations where the water depth is decreasing year by year because of dredged-material placement. Depth-averaged velocities computed by CH3D-WES at the three locations on Figure 26 are given in Figures 32-36.

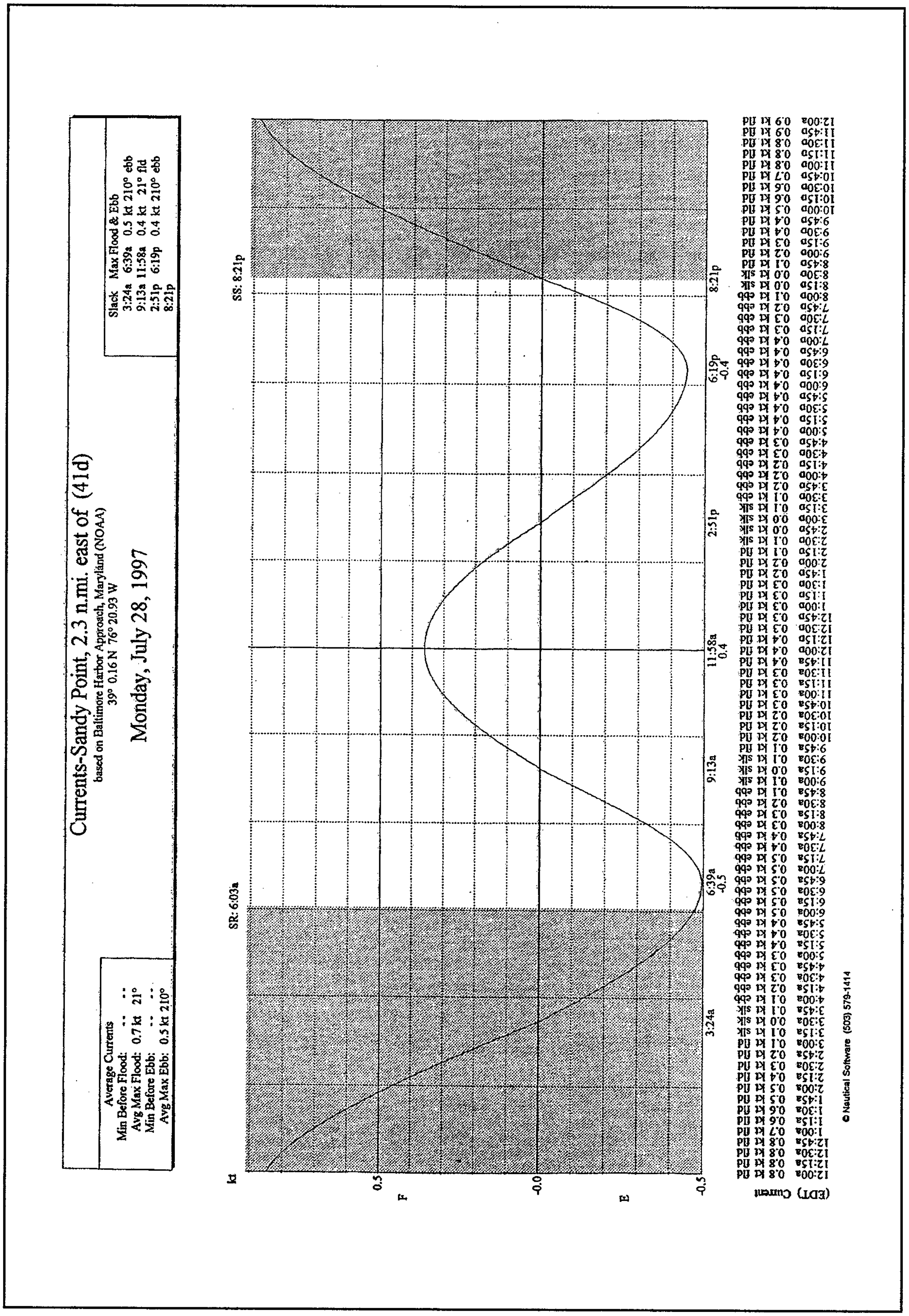


Figure 22. Predicted tidal current at Sandy Point

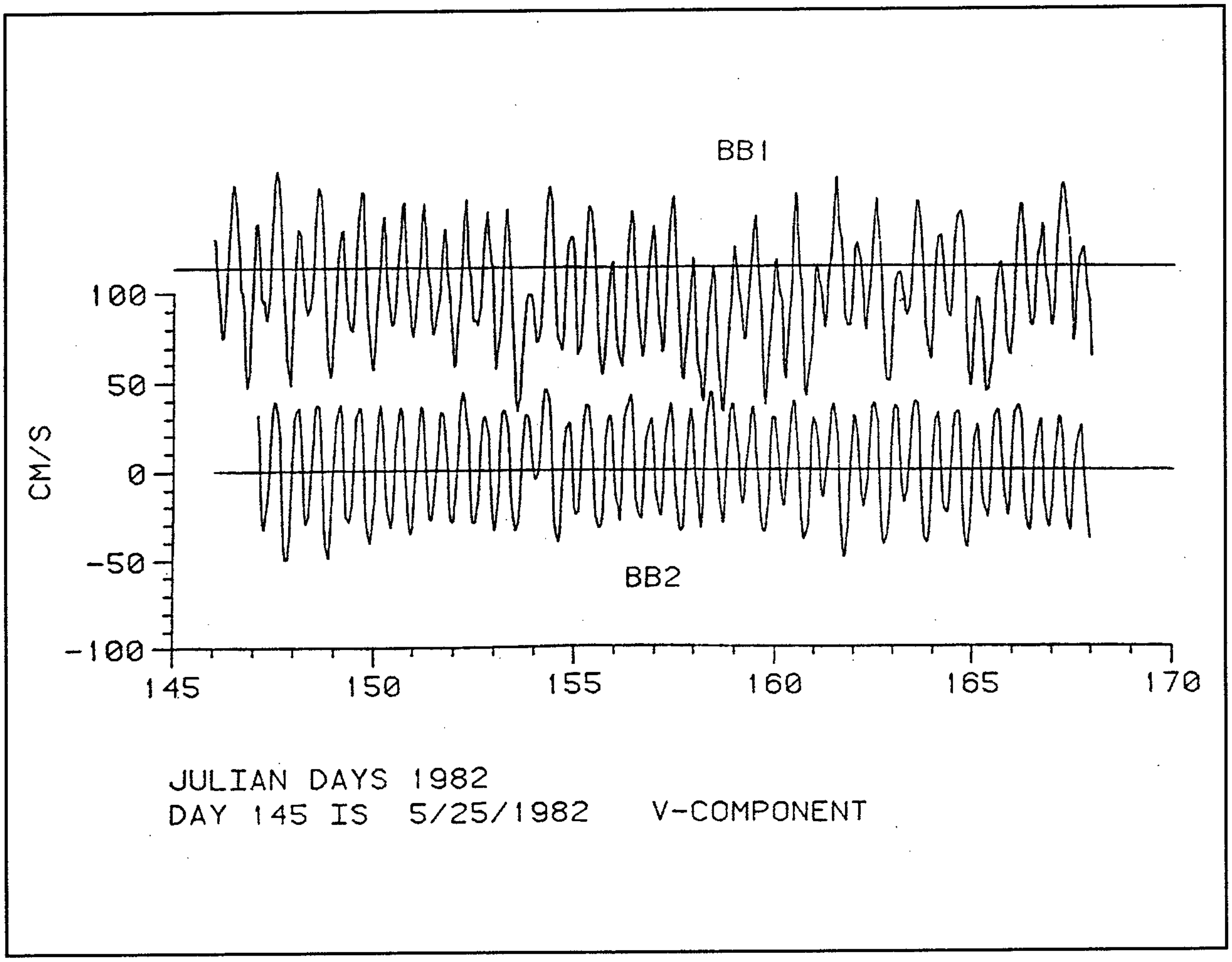
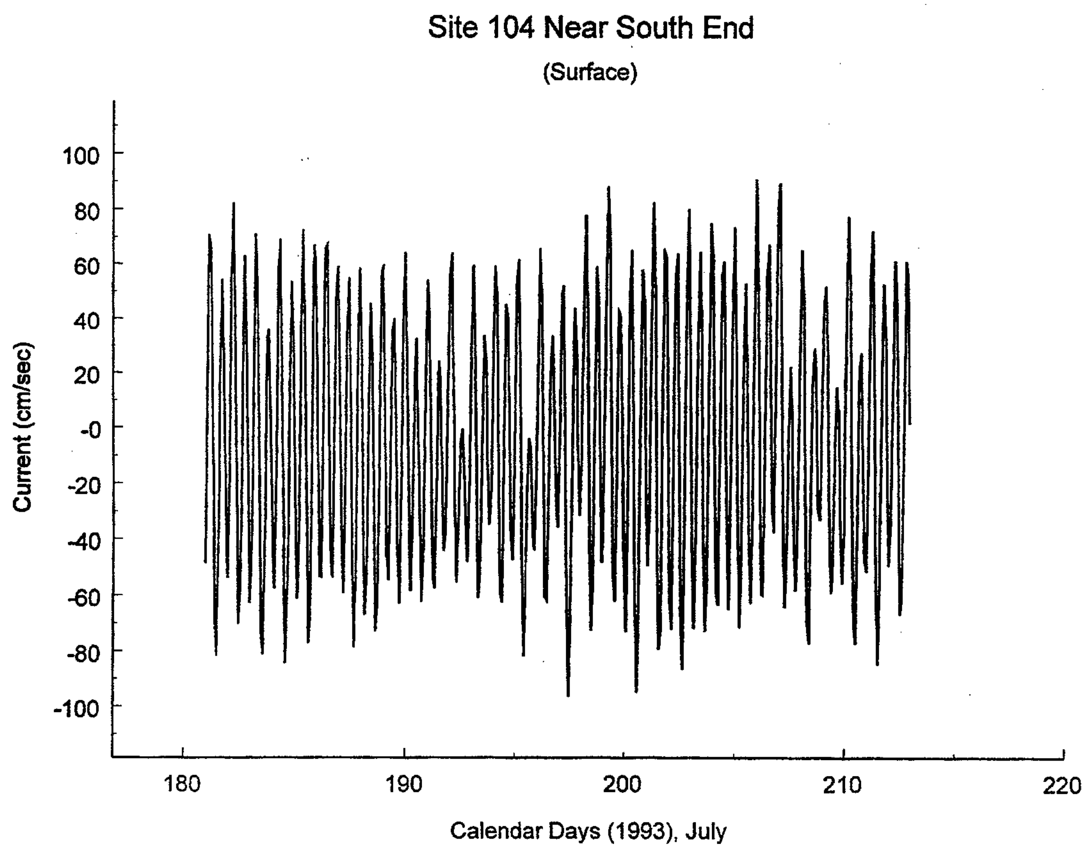
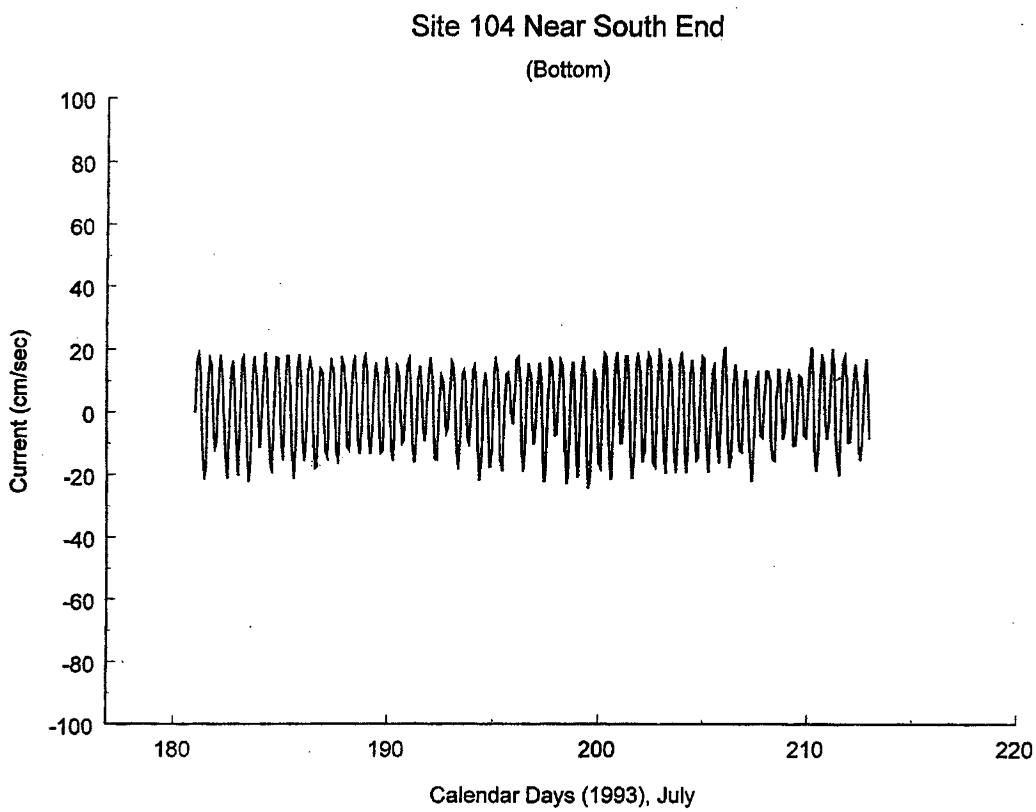


Figure 23. Velocity data from Hamilton and Boicourt (1984) at Bay Bridge (BB1 is at 2.4 m, and BB2 is at 16.8 m)



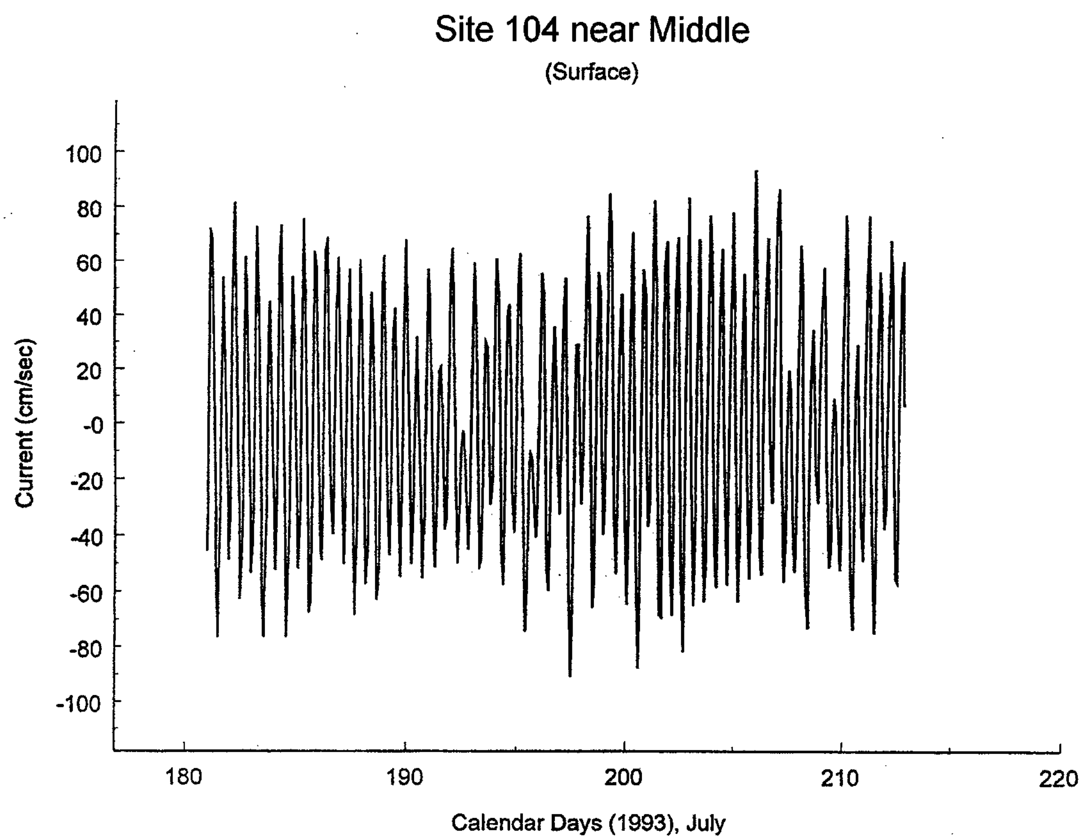
a. near surface

Figure 24. Computed velocity in southern part of Site 104 (Continued)



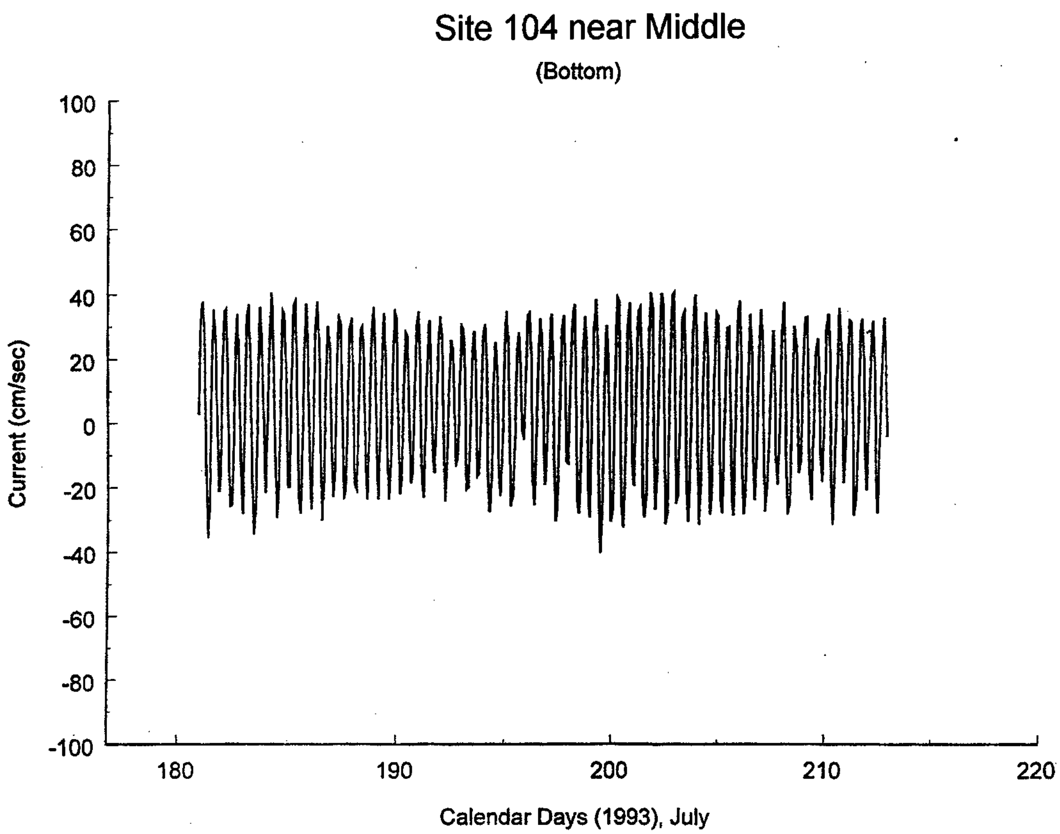
b. near bottom

Figure 24. (Concluded)



a. near surface

Figure 25. Computed velocity near middle of Site 104 (Continued)



b. near bottom

Figure 25. (Concluded)

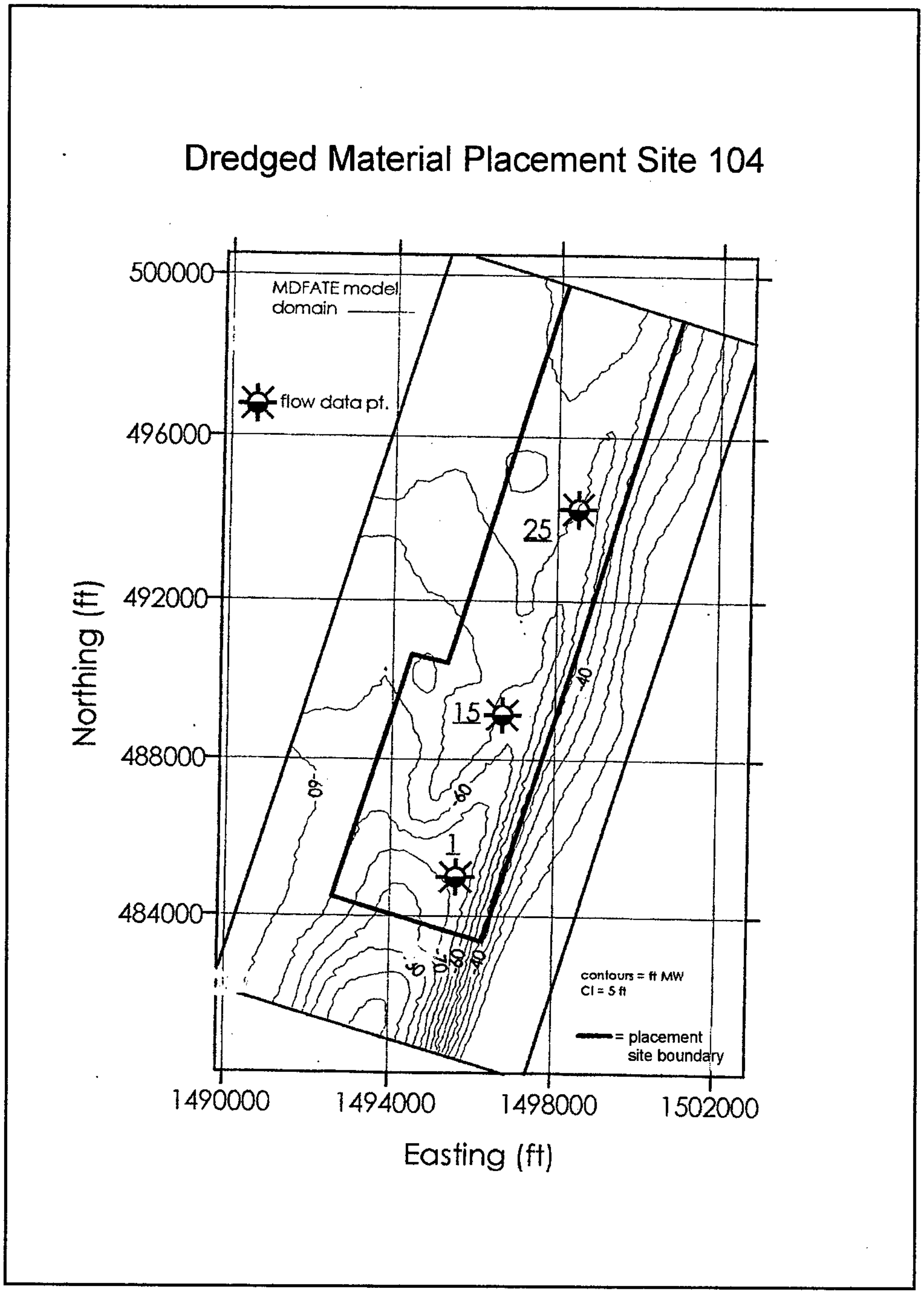


Figure 26. Locations for presenting hydrodynamic results at Site 104

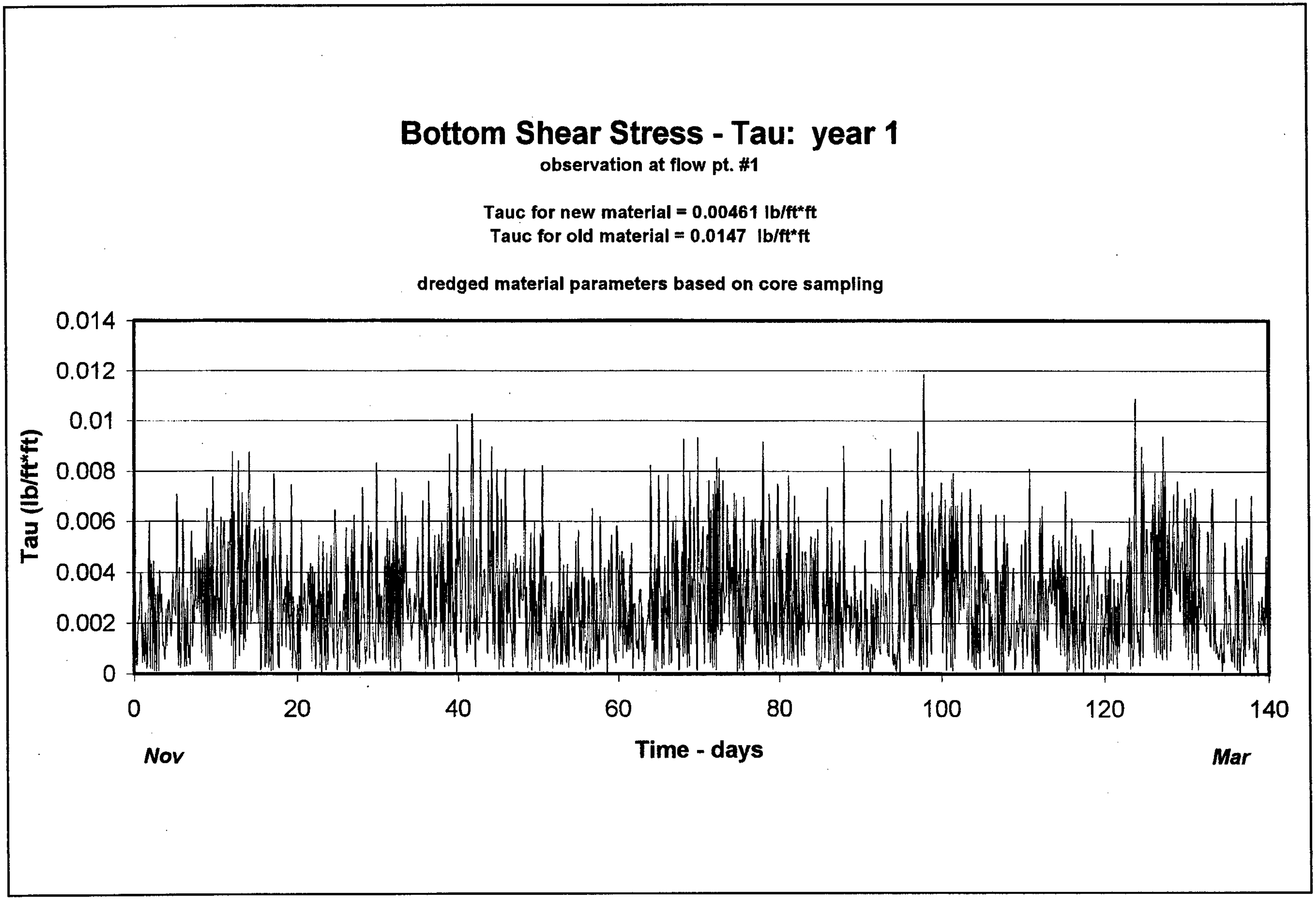


Figure 27. Bottom shear stress for Year 1 (Sheet 1 of 3)

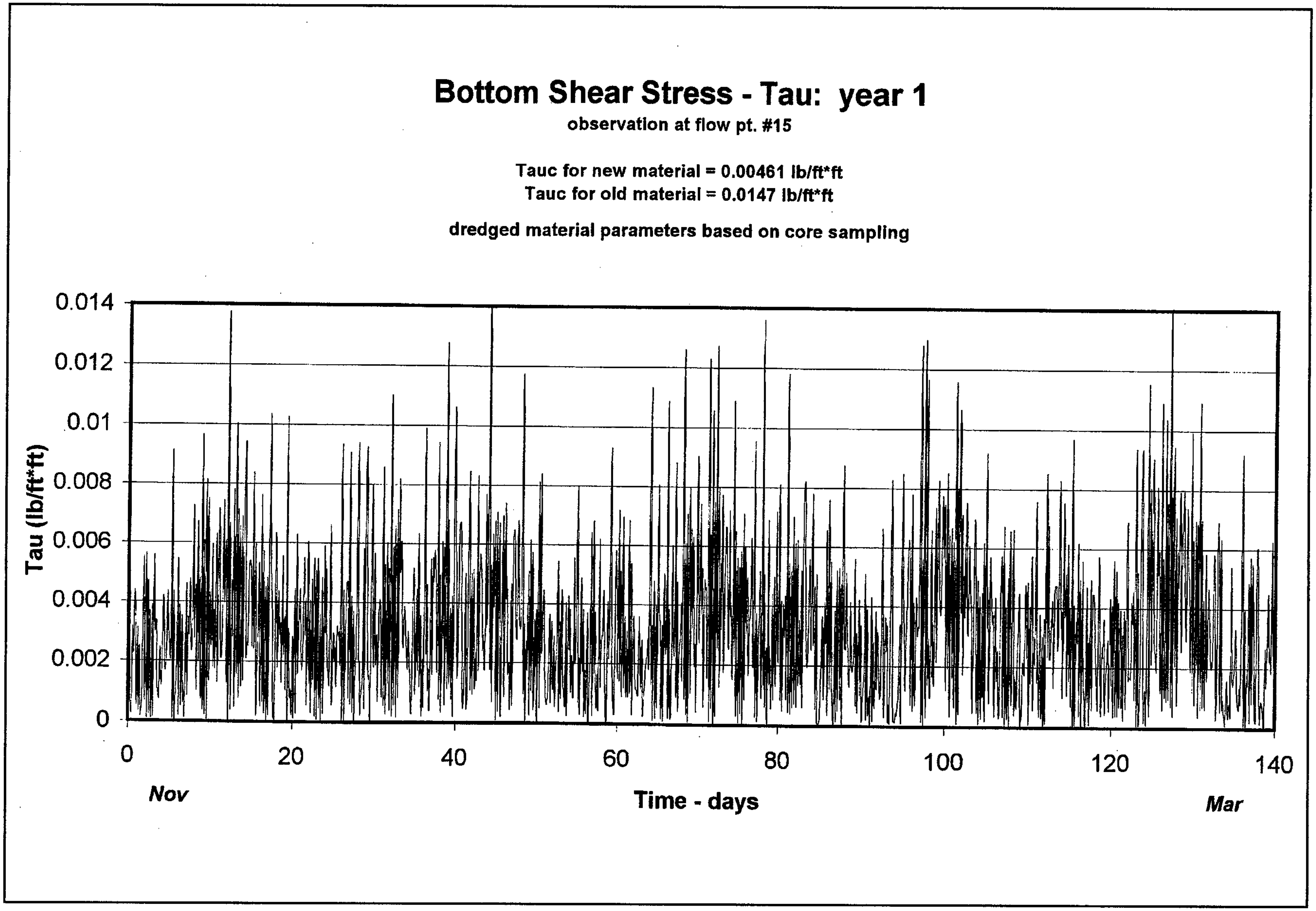


Figure 27. (Sheet 2 of 3)

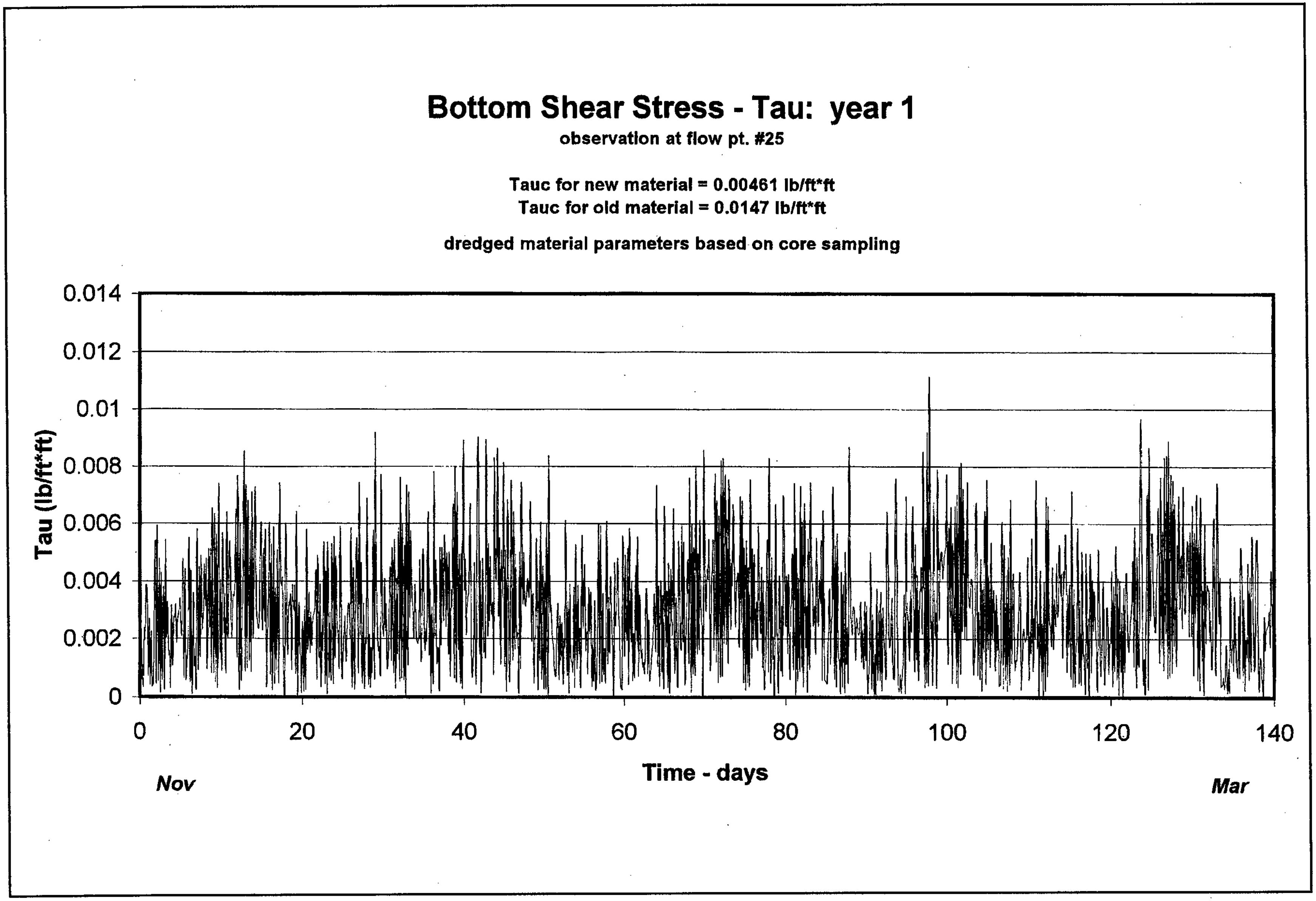


Figure 27. (Sheet 3 of 3)

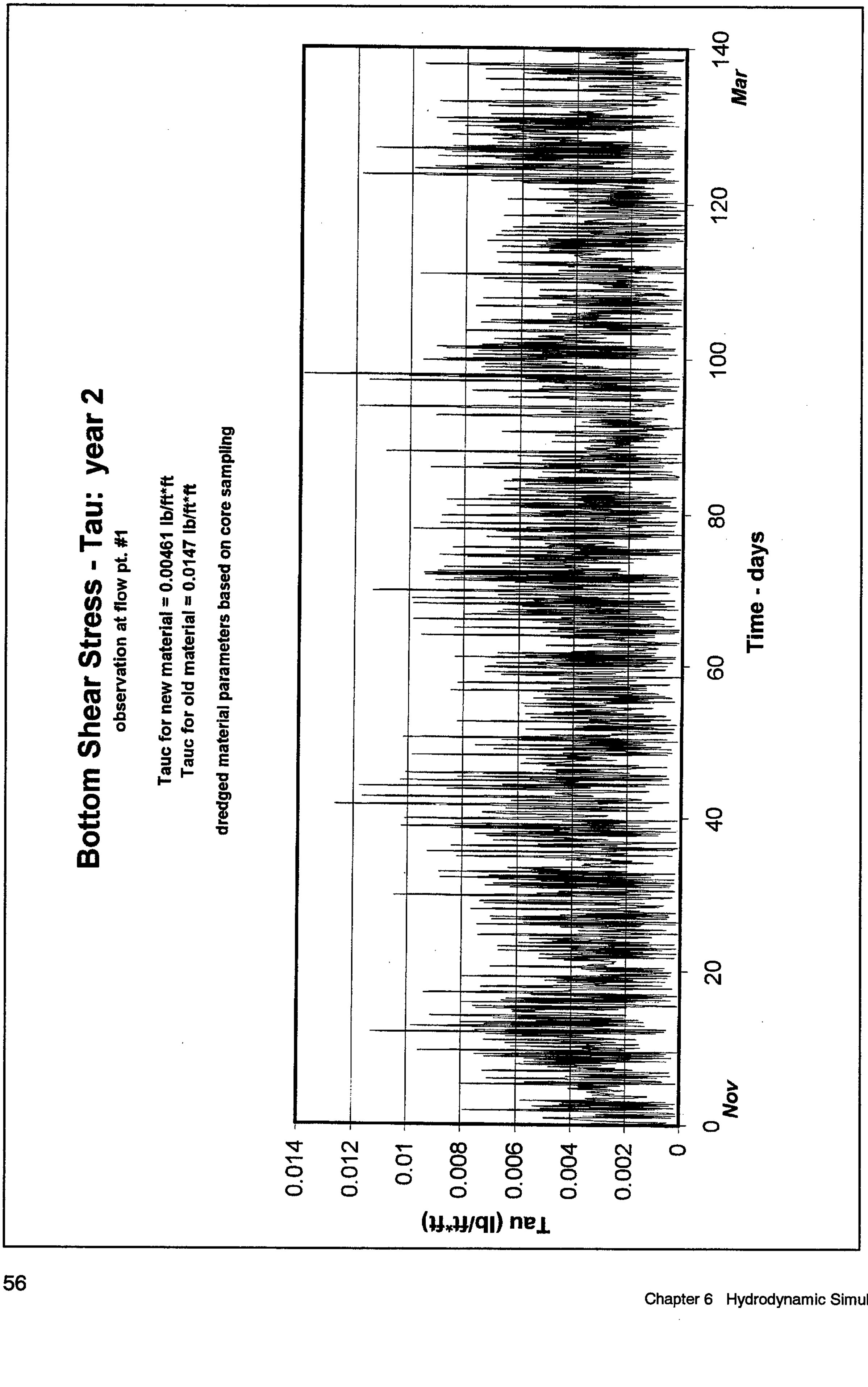


Figure 28. Bottom shear stress for Year 2 (Sheet 1 of 3)

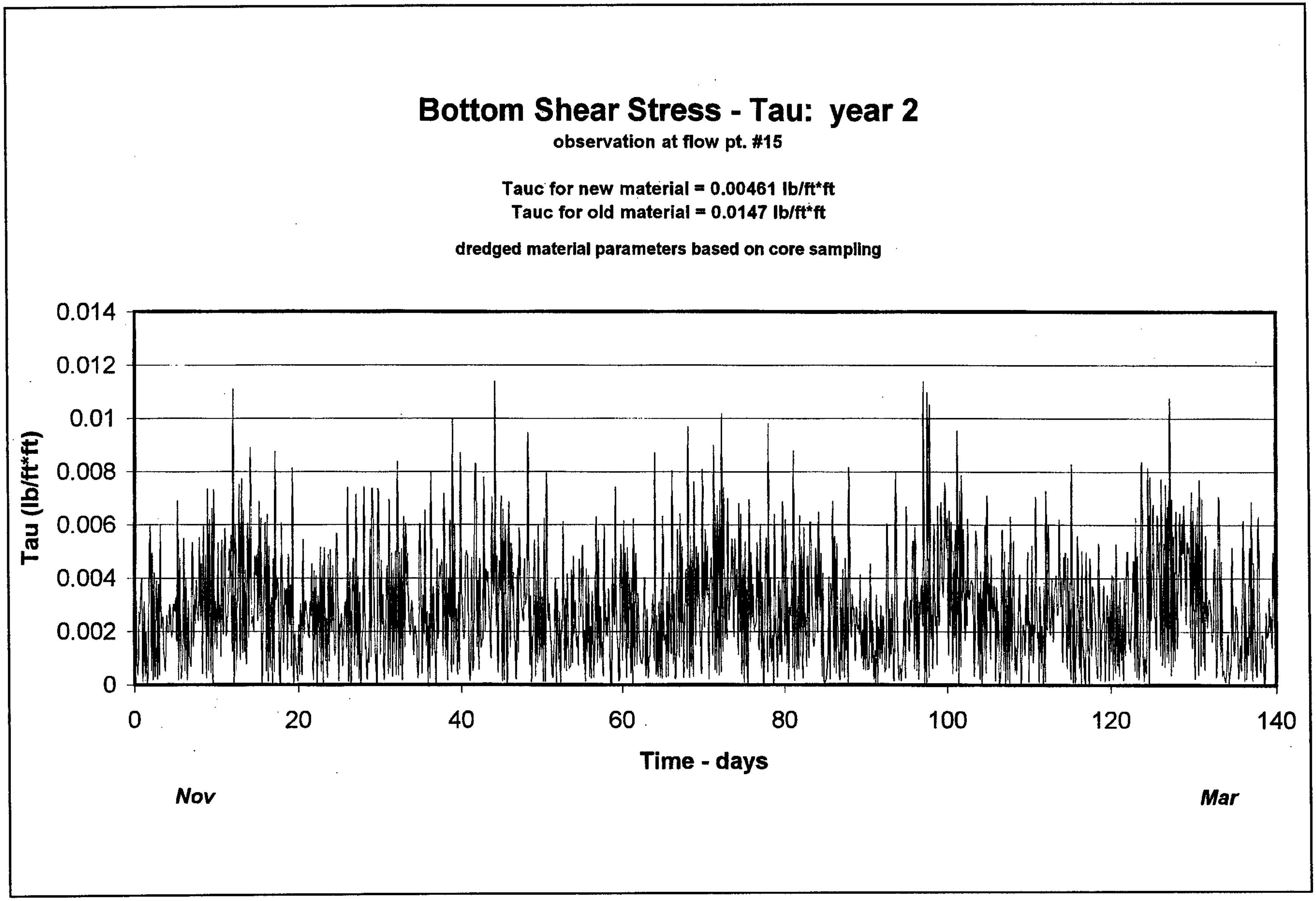


Figure 28. (Sheet 2 of 3)

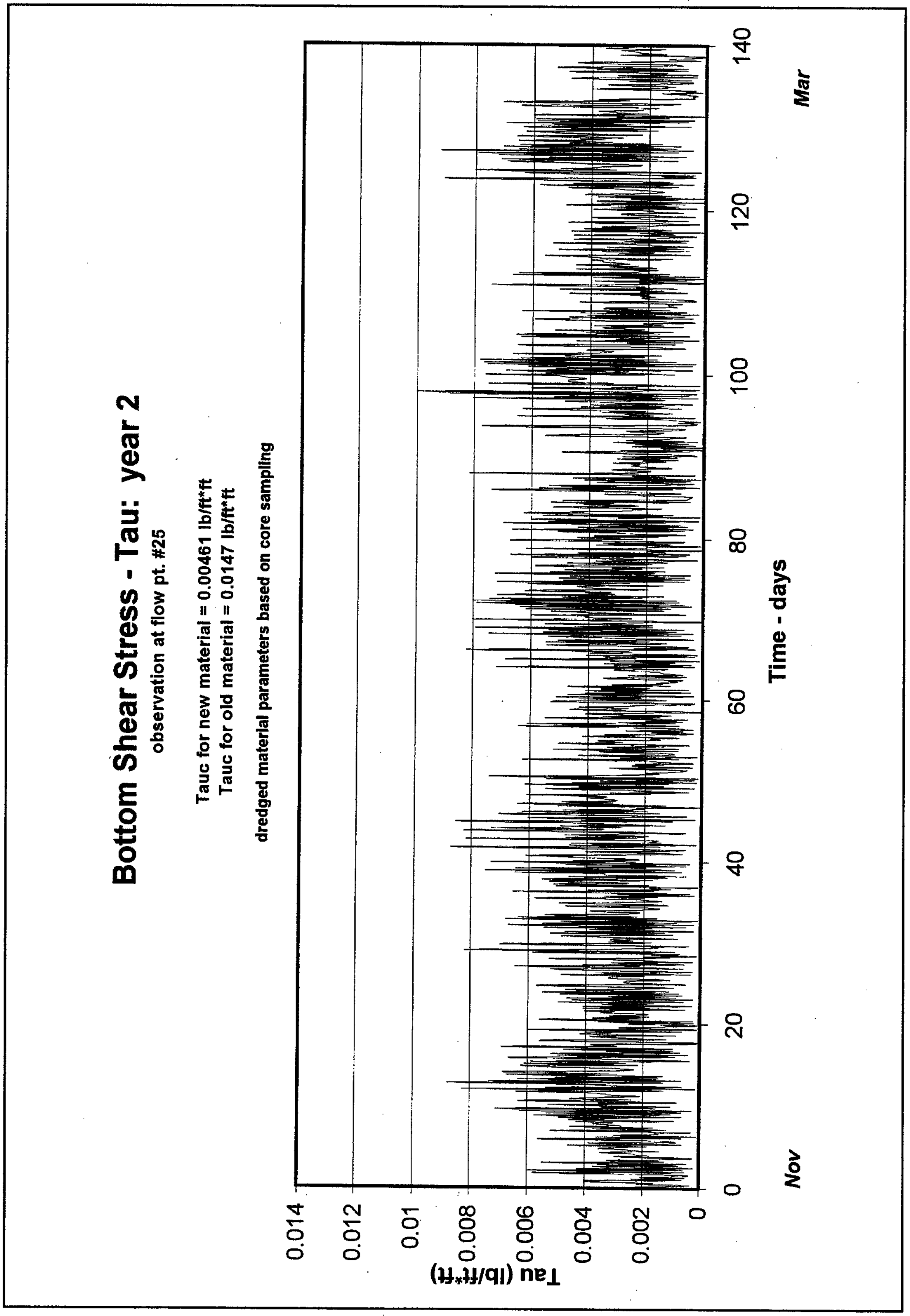


Figure 28.   (Sheet 3 of 3)

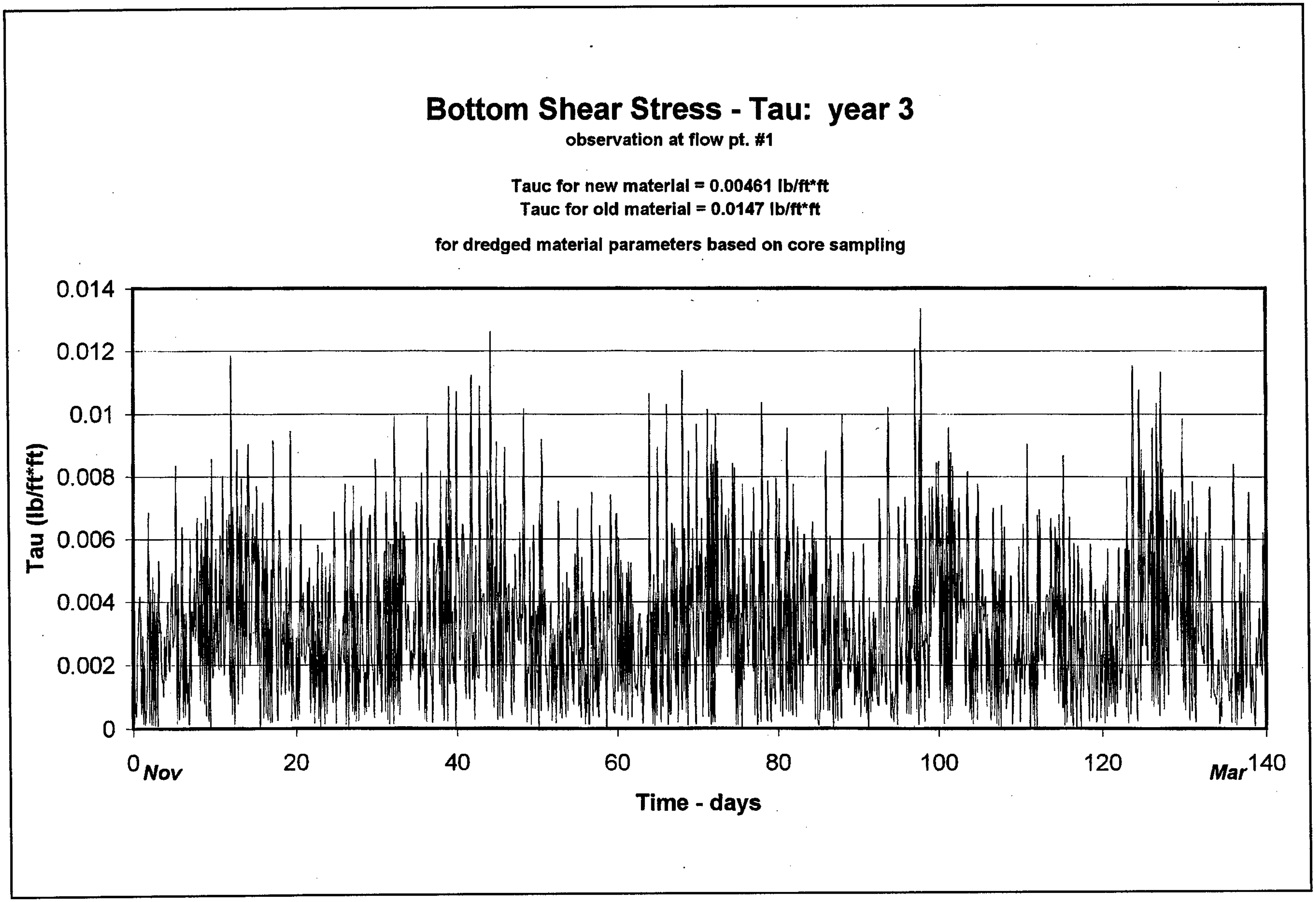


Figure 29. Bottom shear stress for Year 3 (Sheet 1 of 3)

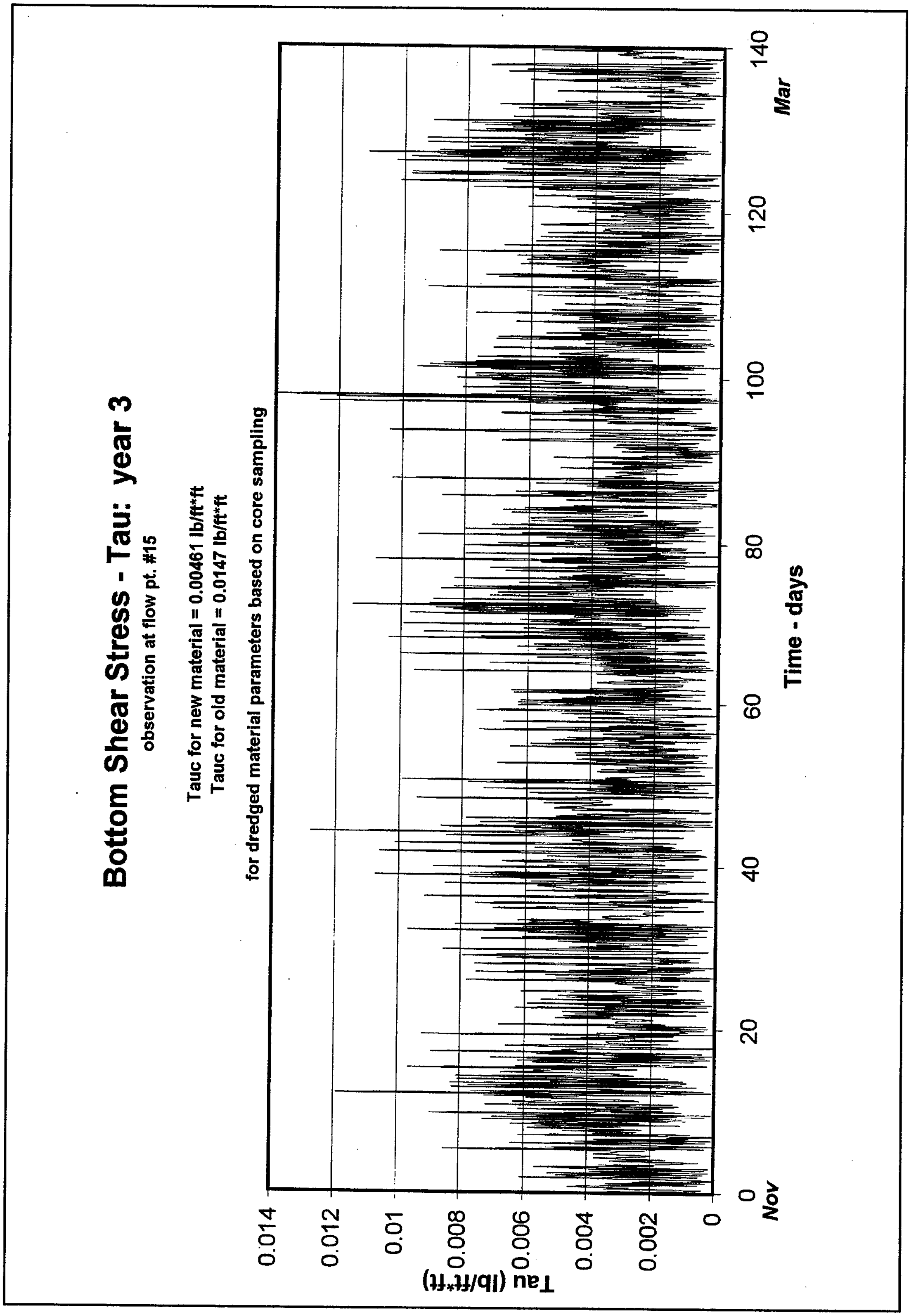


Figure 29. (Sheet 2 of 3)

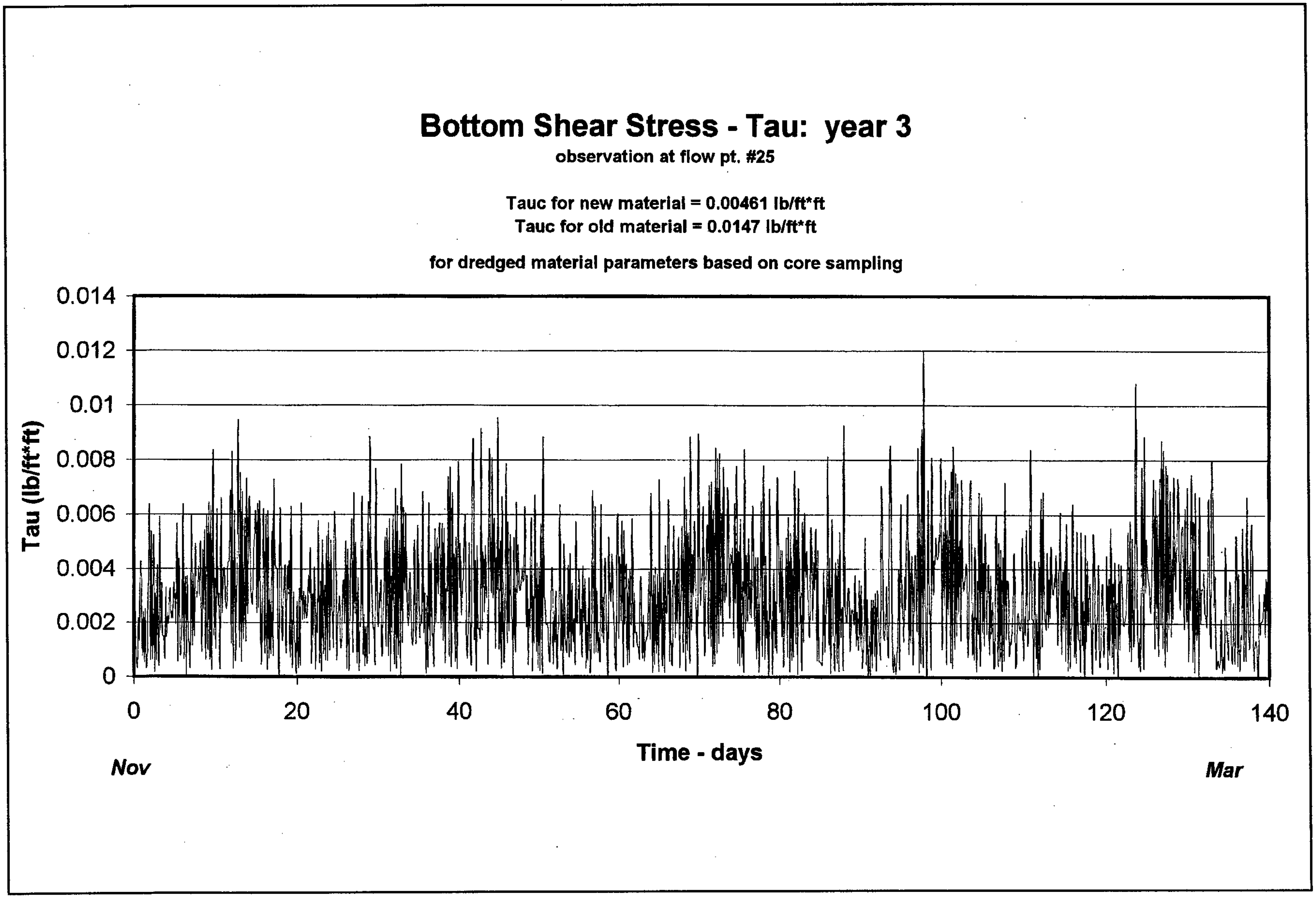


Figure 29. (Sheet 3 of 3)

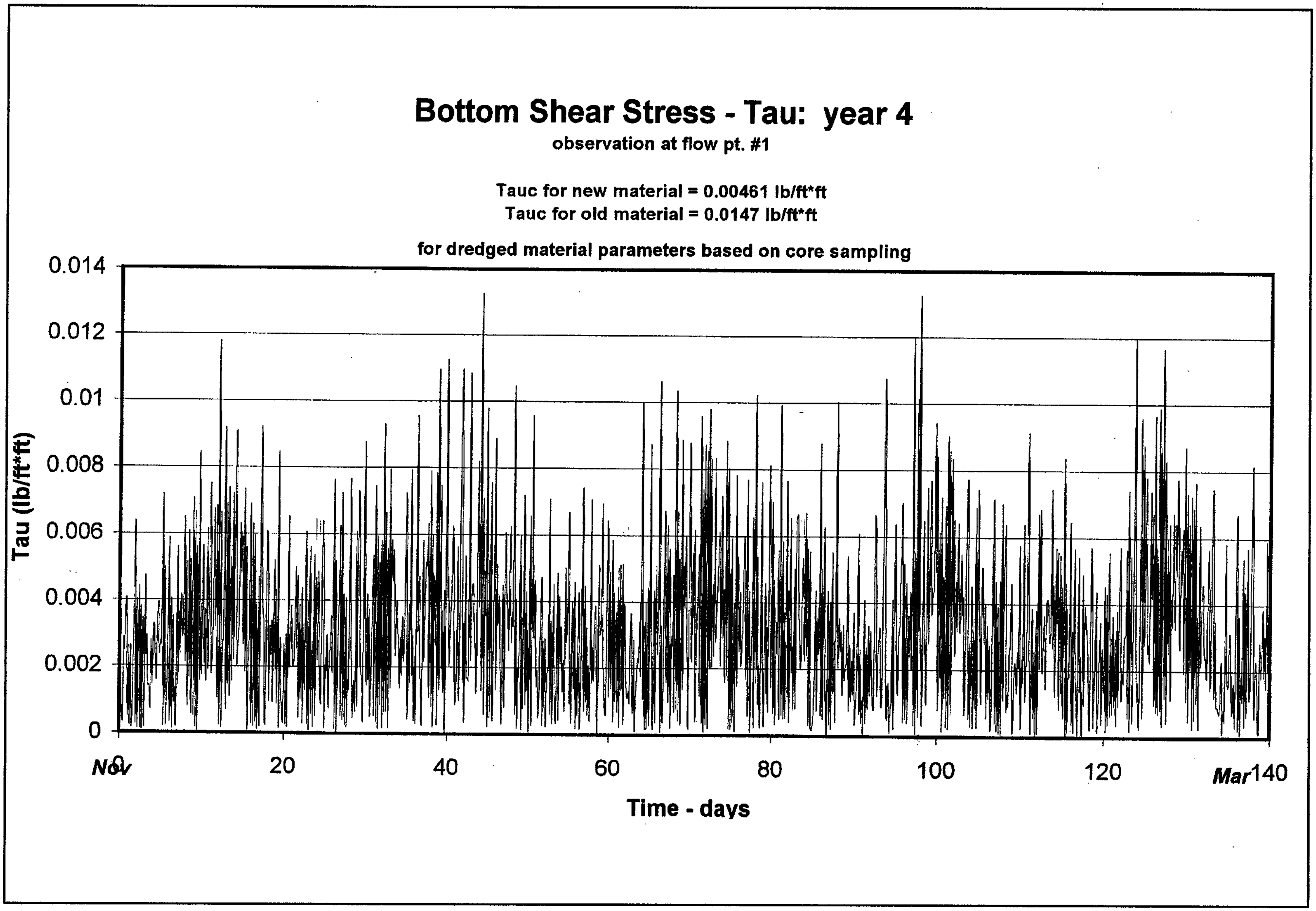


Figure 30. Bottom shear stress for Year 4 (Sheet 1 of 3)

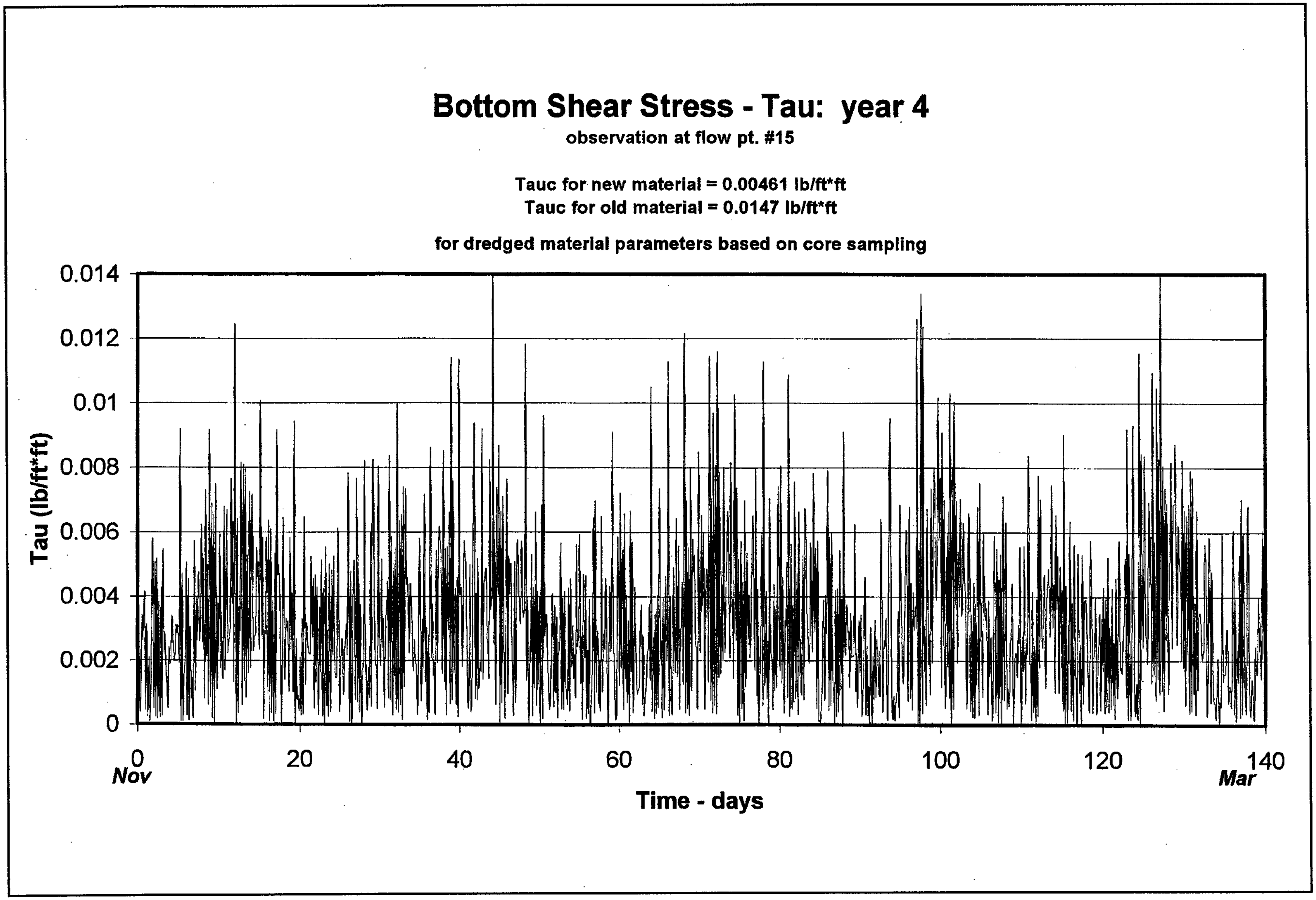


Figure 30. (Sheet 2 of 3)

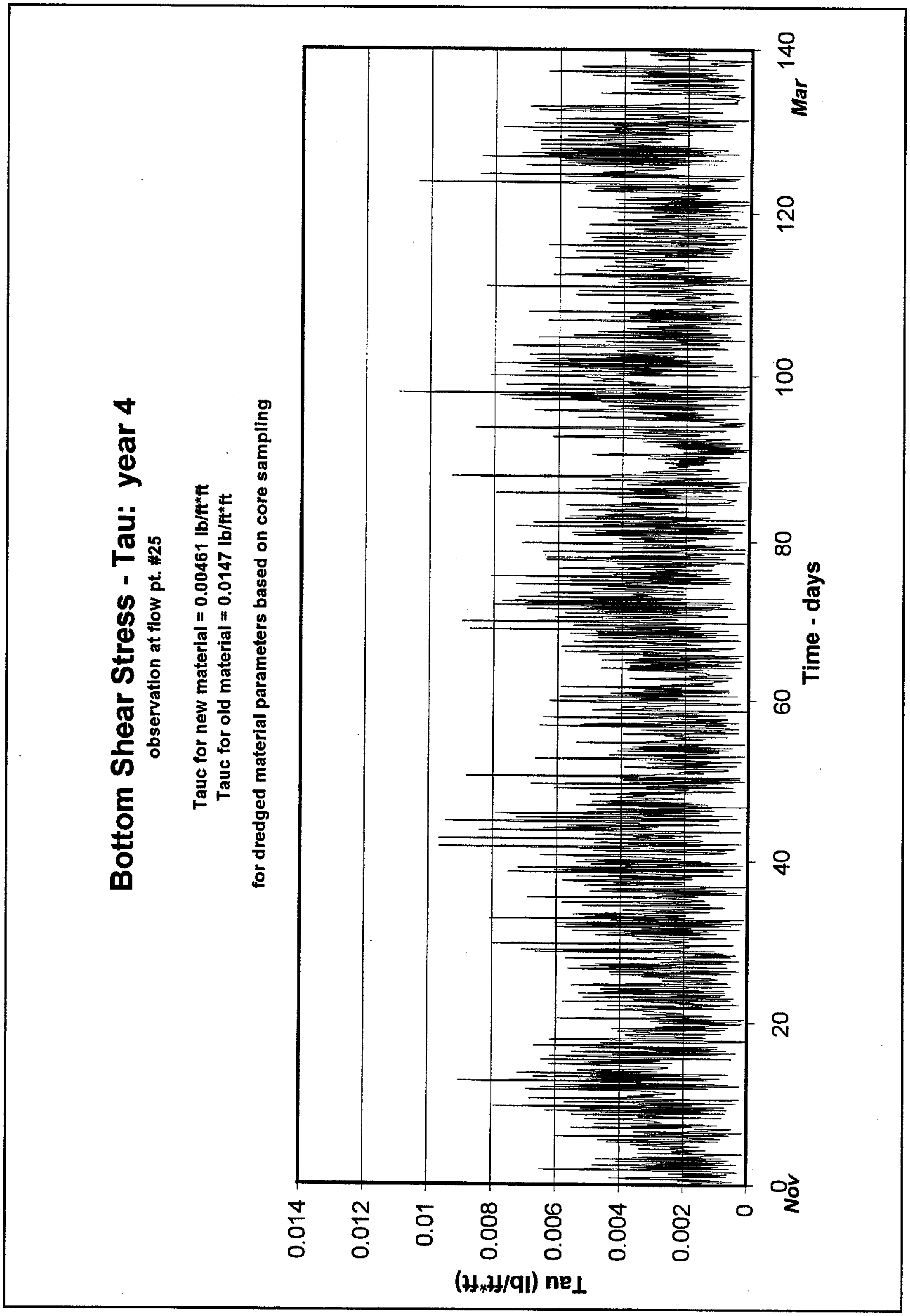


Figure 30. (Sheet 3 of 3)

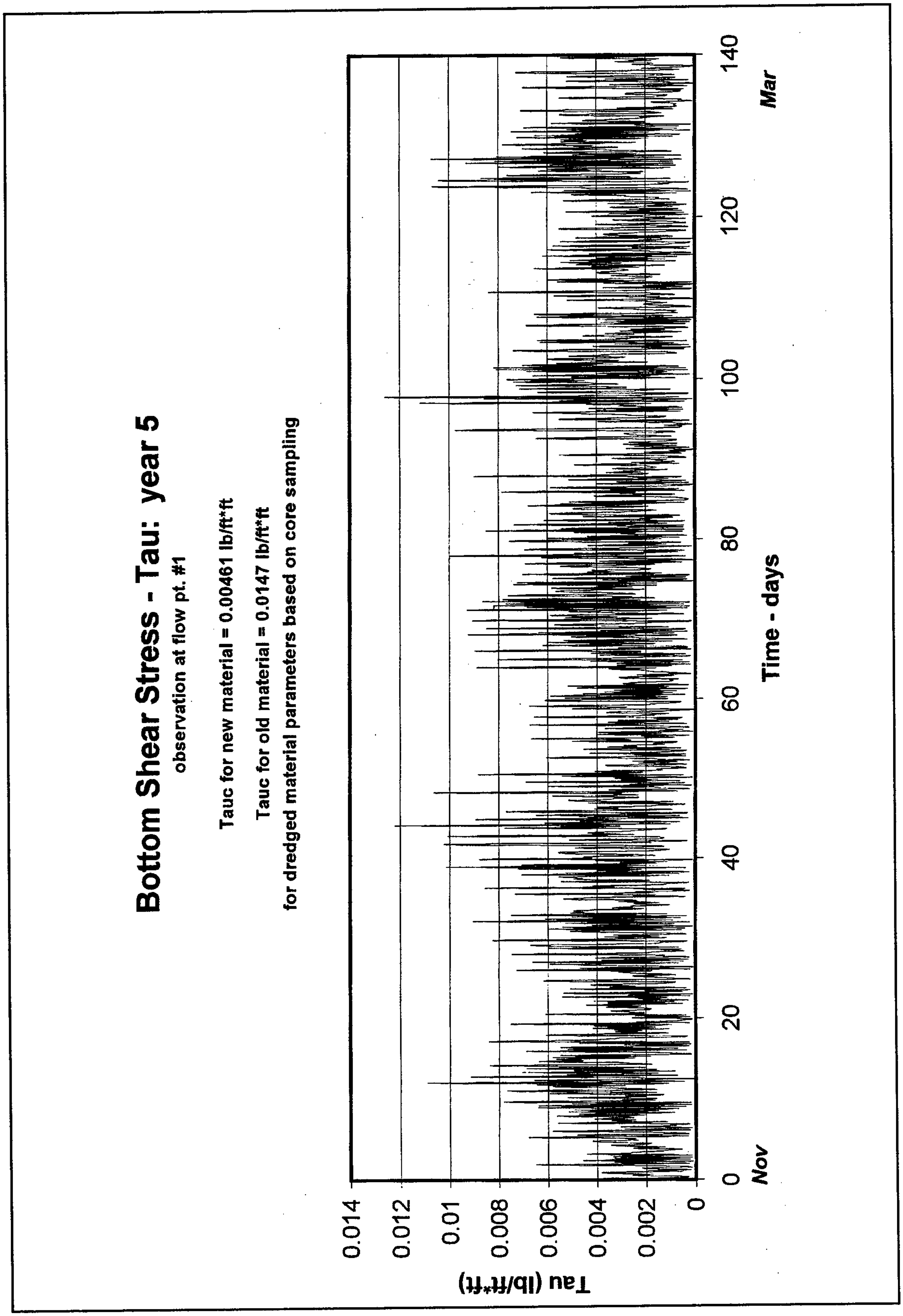


Figure 31. Bottom shear stress for Year 5 (Sheet 1 of 3)

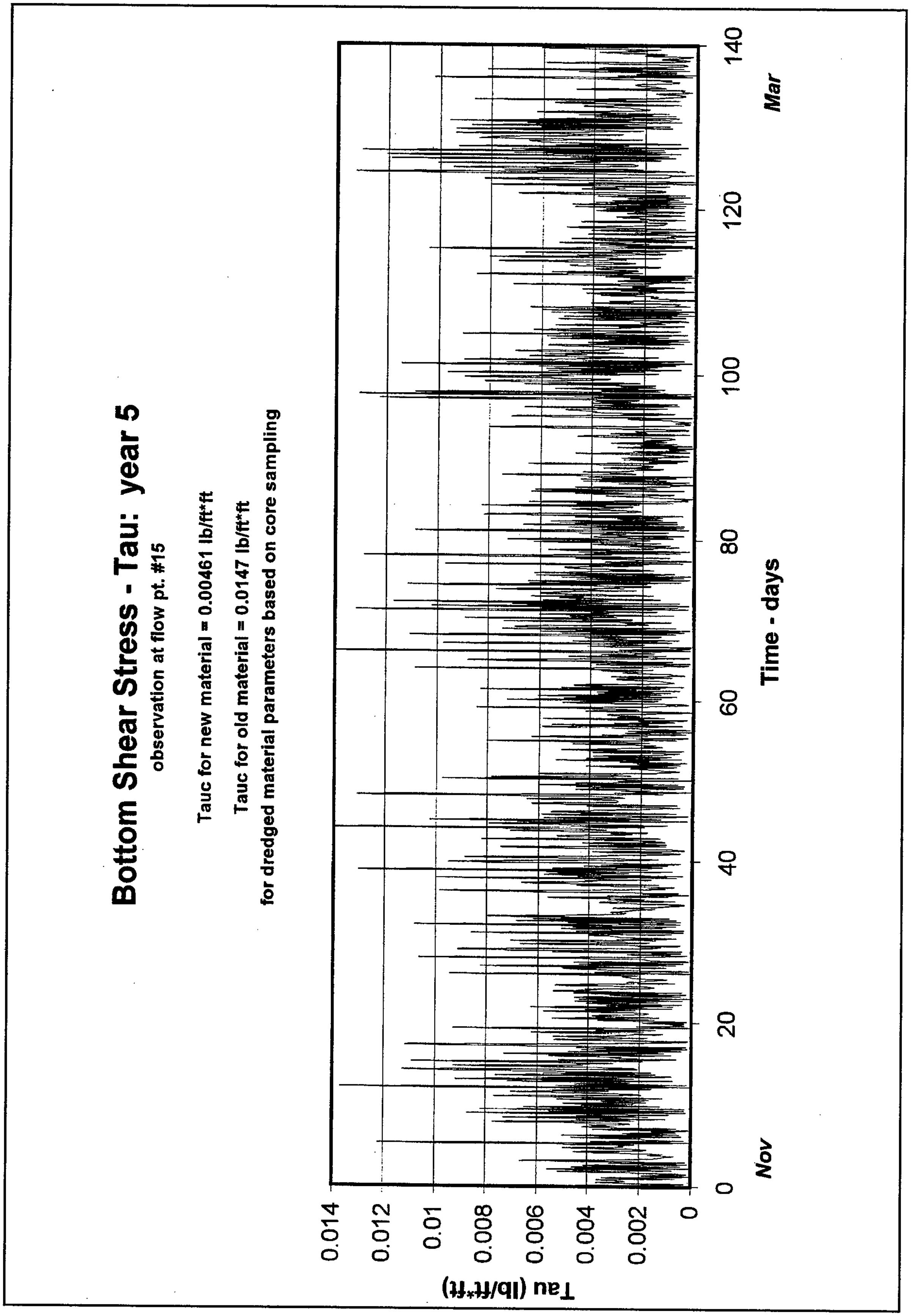
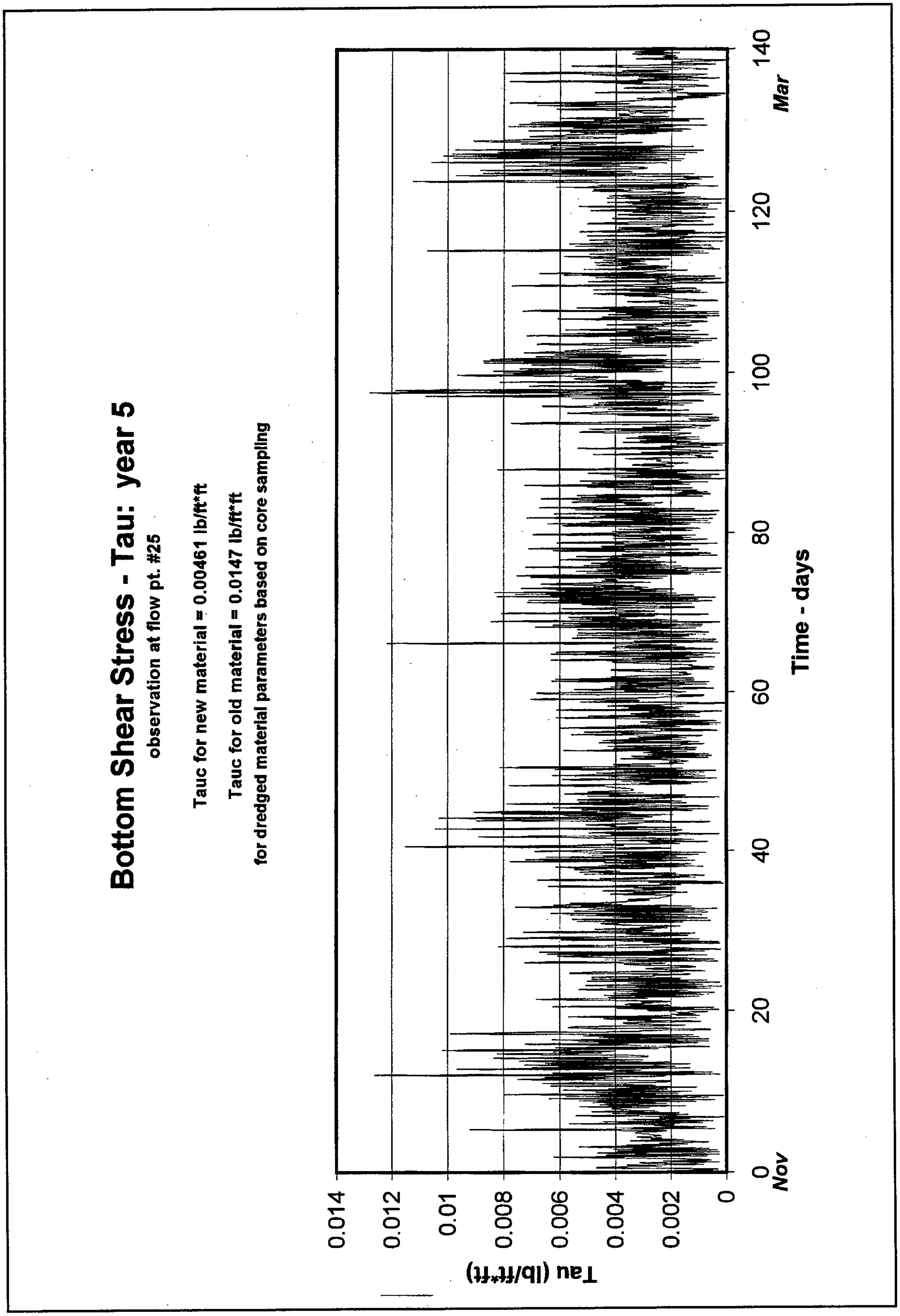


Figure 31. (Sheet 2 of 3)



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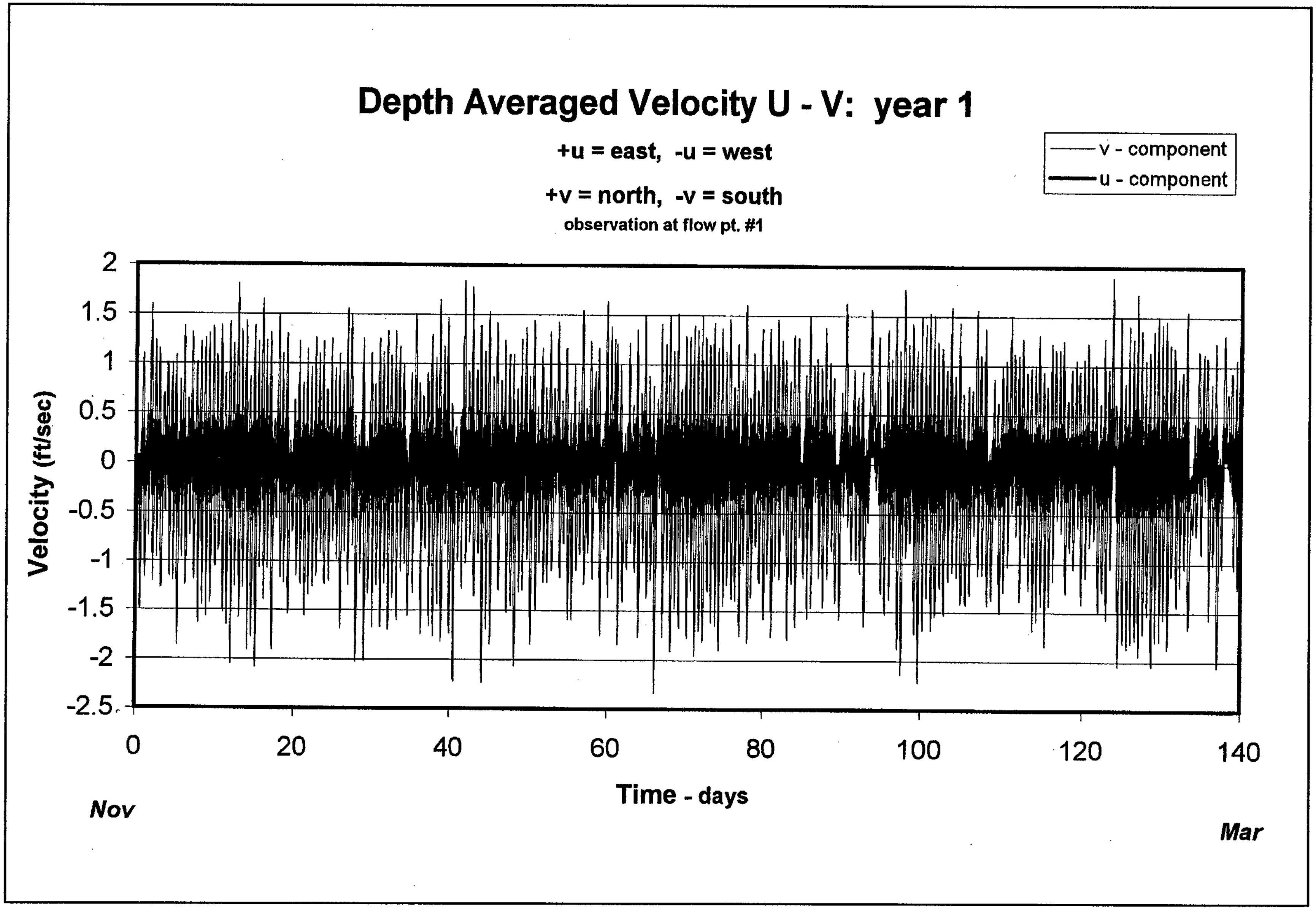

Figure 32. Vertically averaged velocity for Year 1 (Sheet 1 of 3)

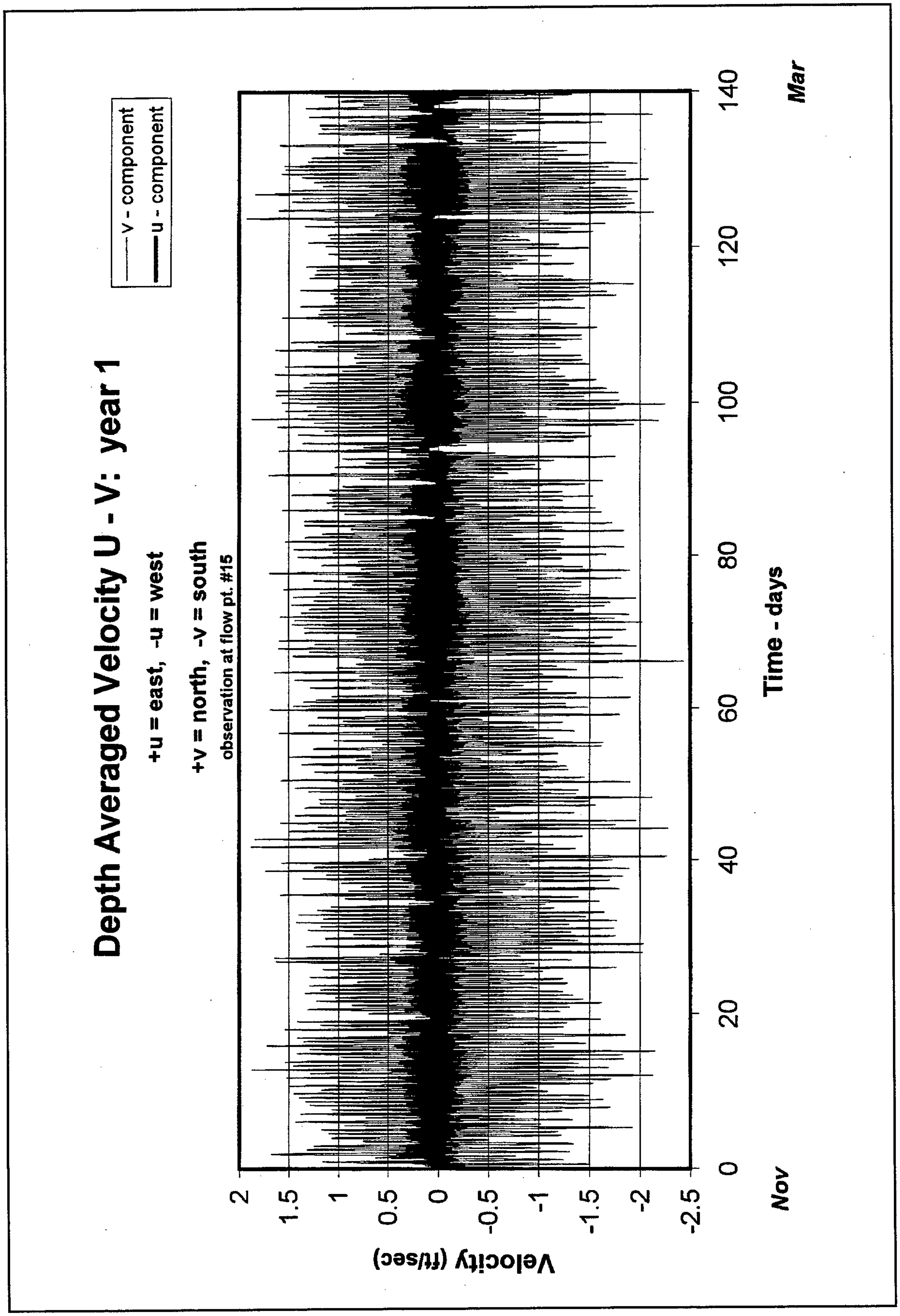

Figure 32. (Sheet 2 of 3)

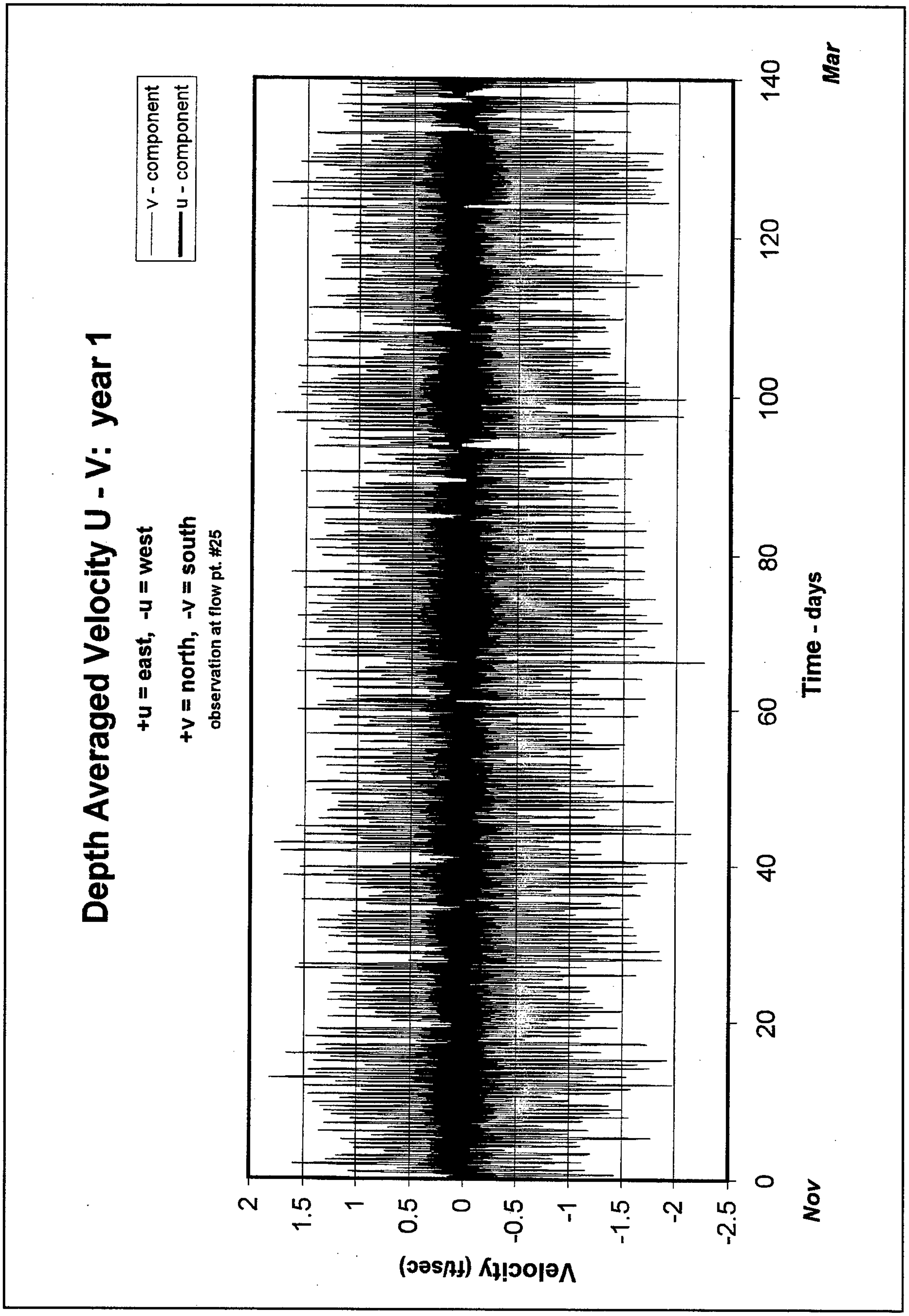

Figure 32. (Sheet 3 of 3)

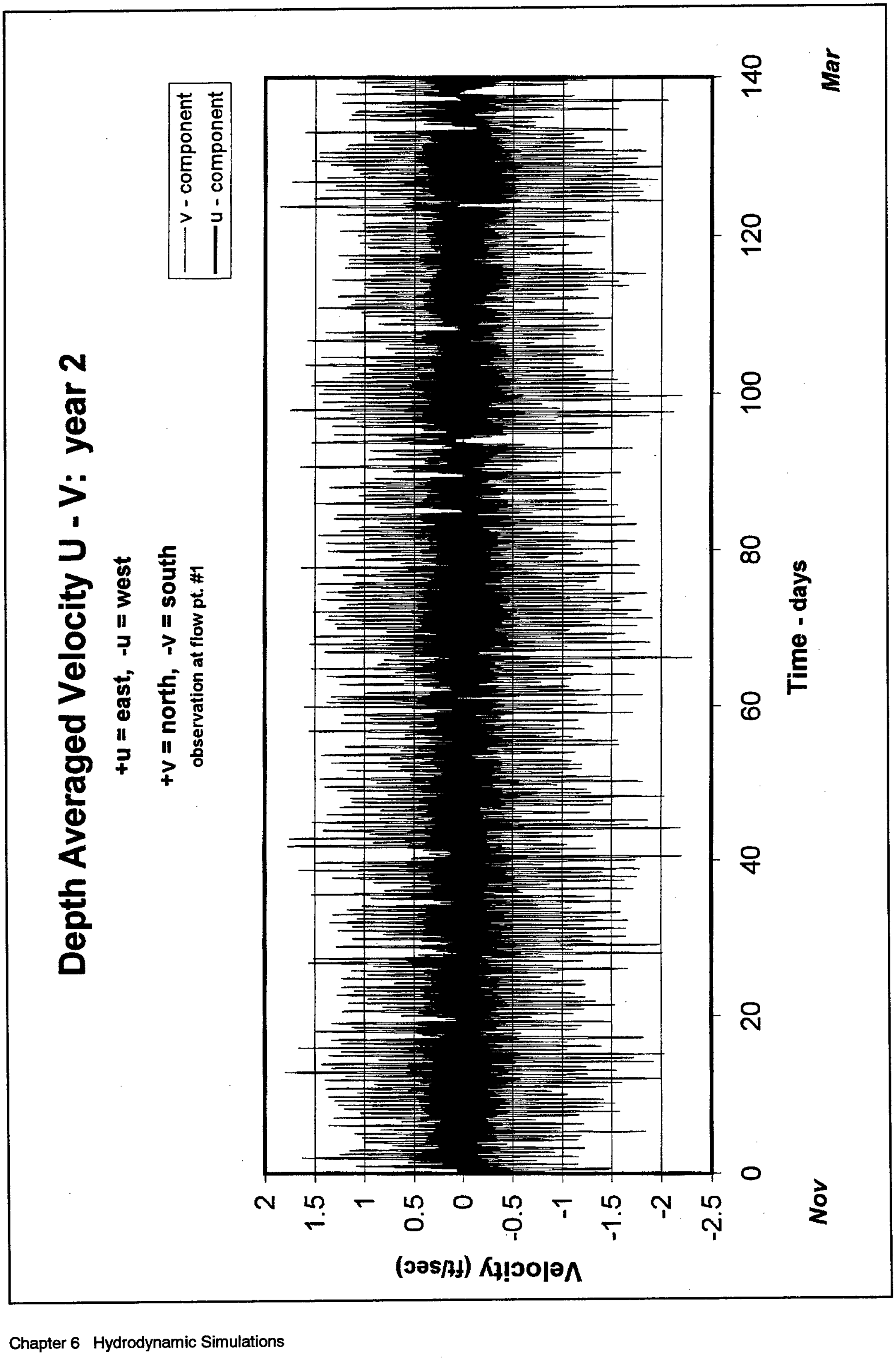

Figure 33. Vertically averaged velocity for Year 2 (Sheet 1 of 3)

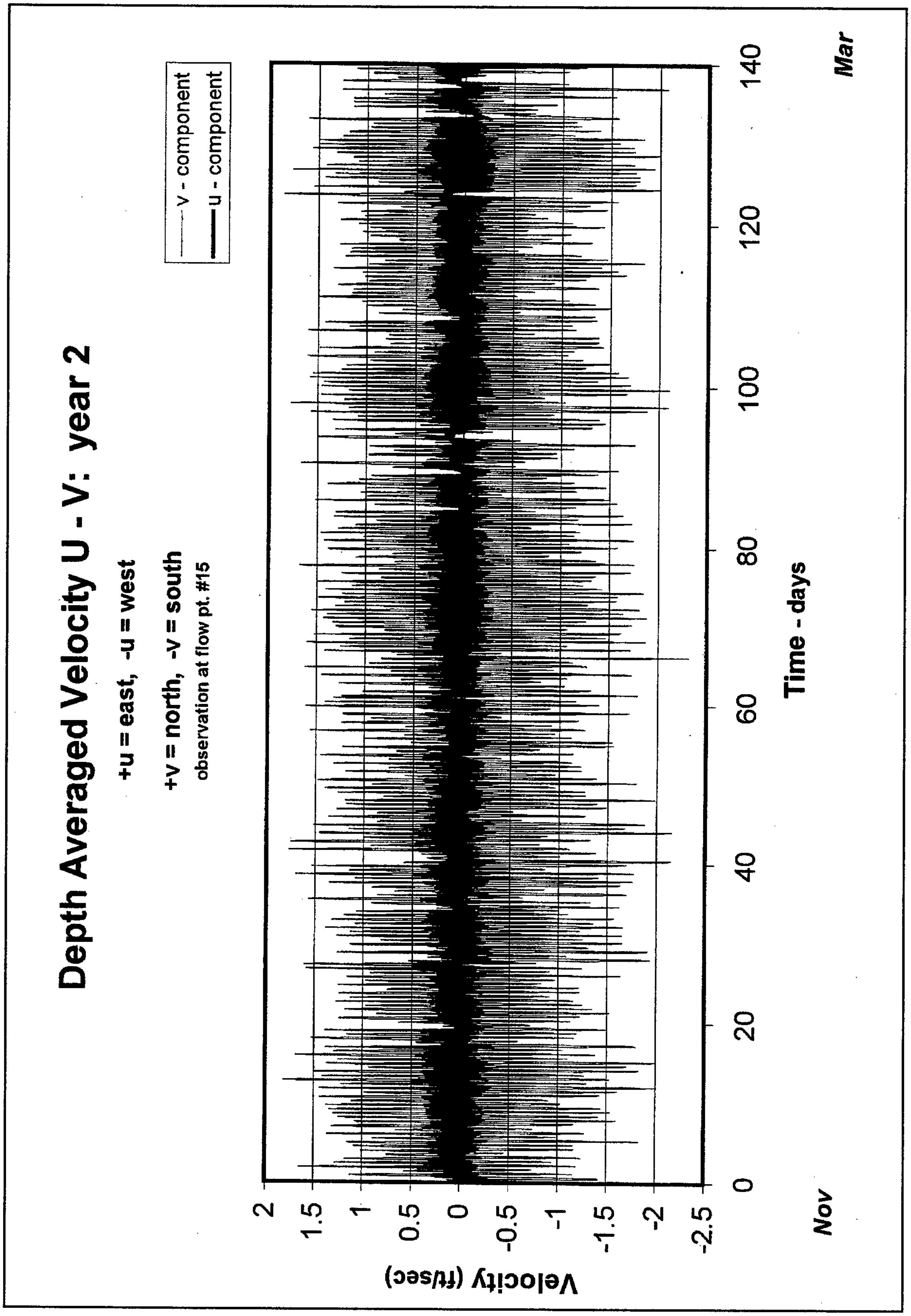

Figure 33. (Sheet 2 of 3)

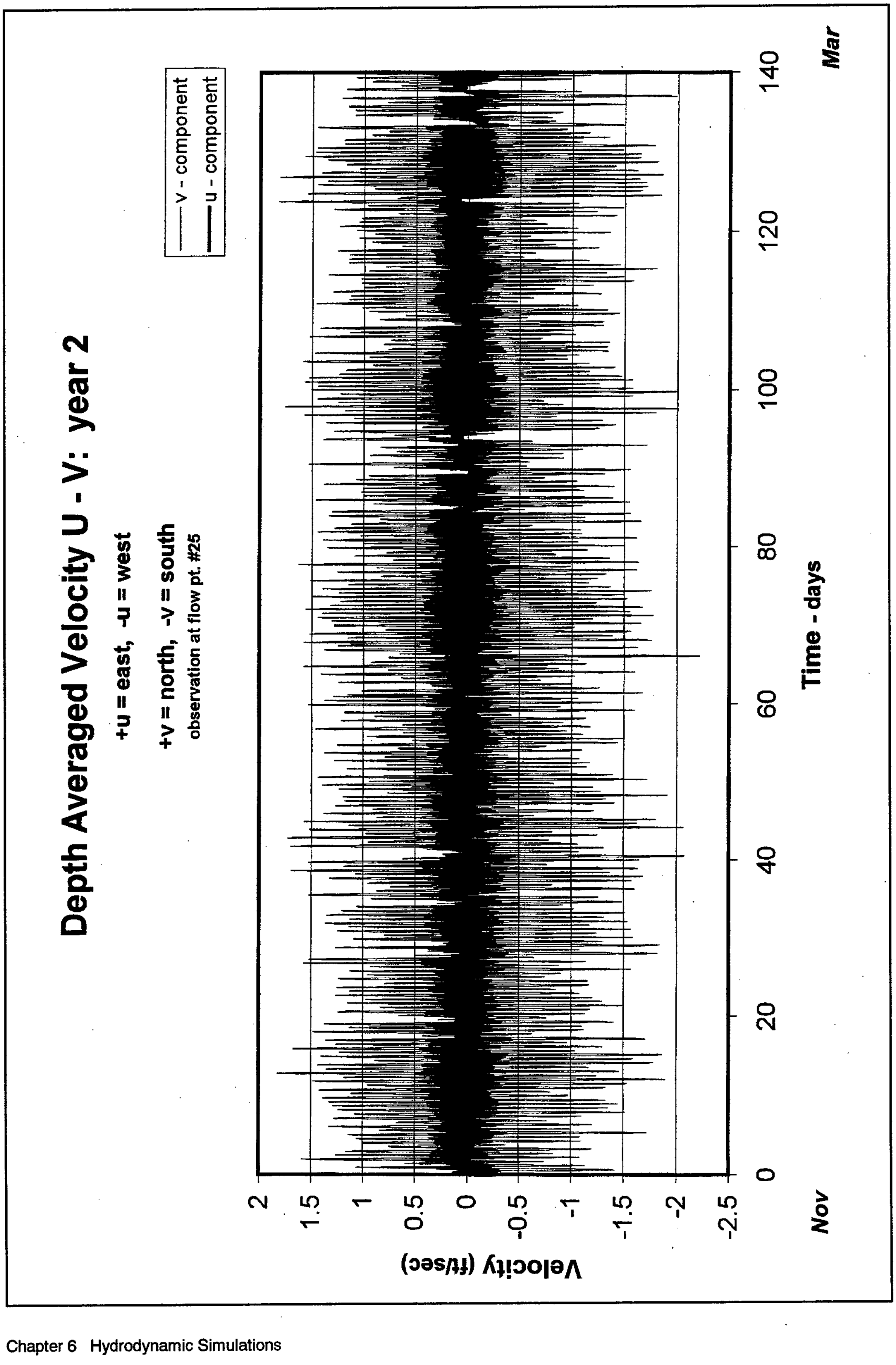

Figure 33. (Sheet 3 of 3)

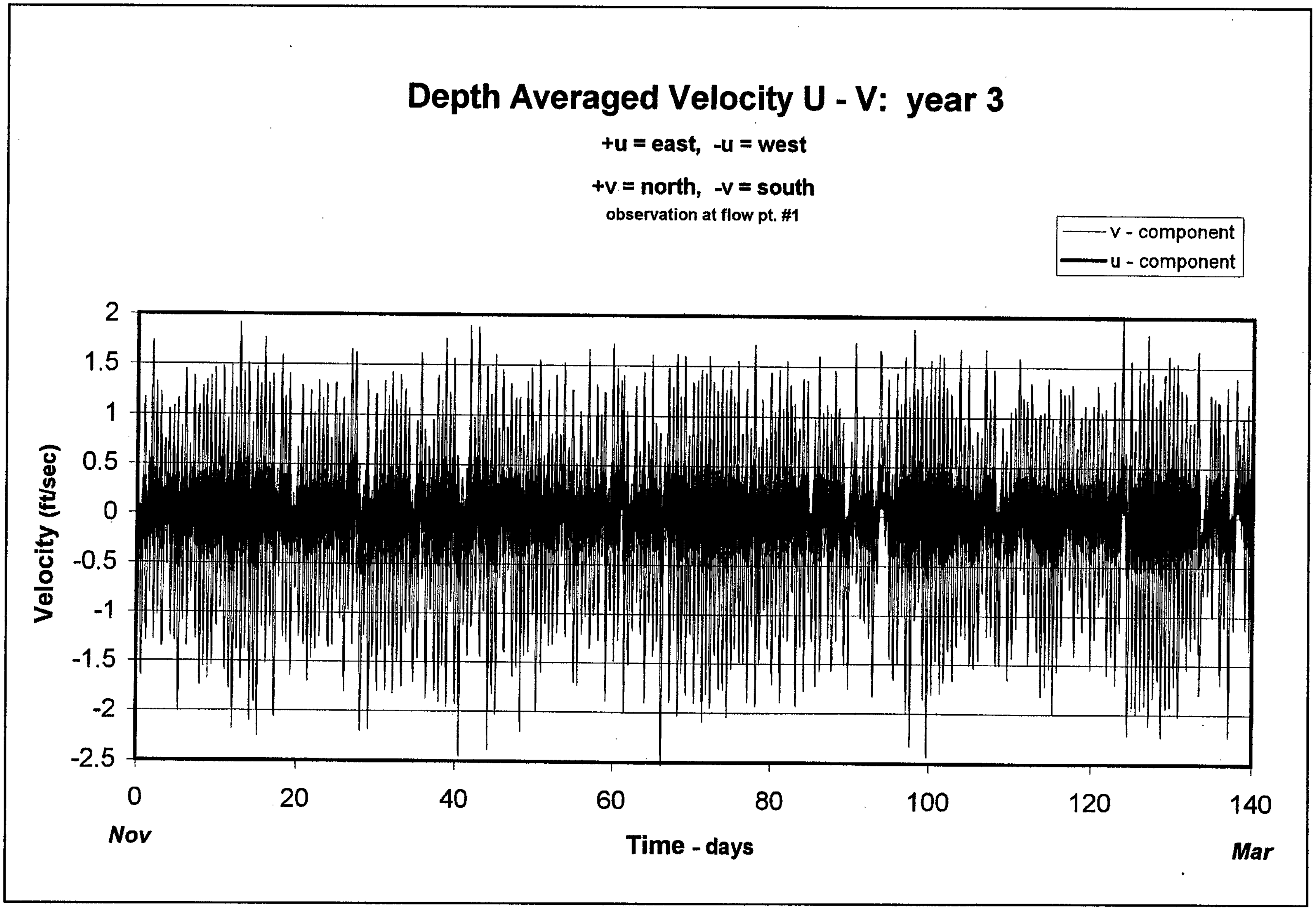

Figure 34. Vertically averaged velocity for Year 3 (Sheet 1 of 3)

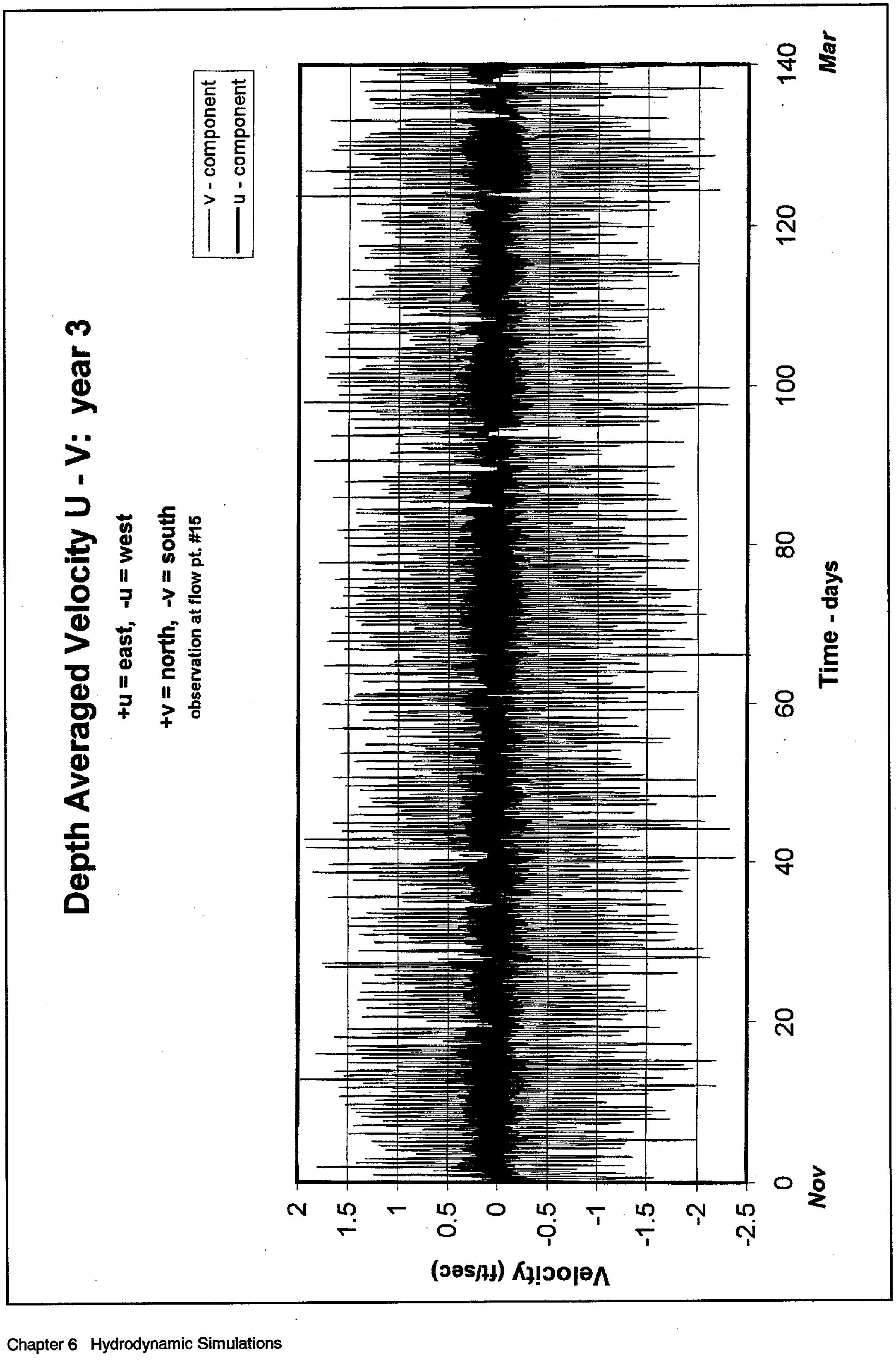

Figure 34. (Sheet 2 of 3)

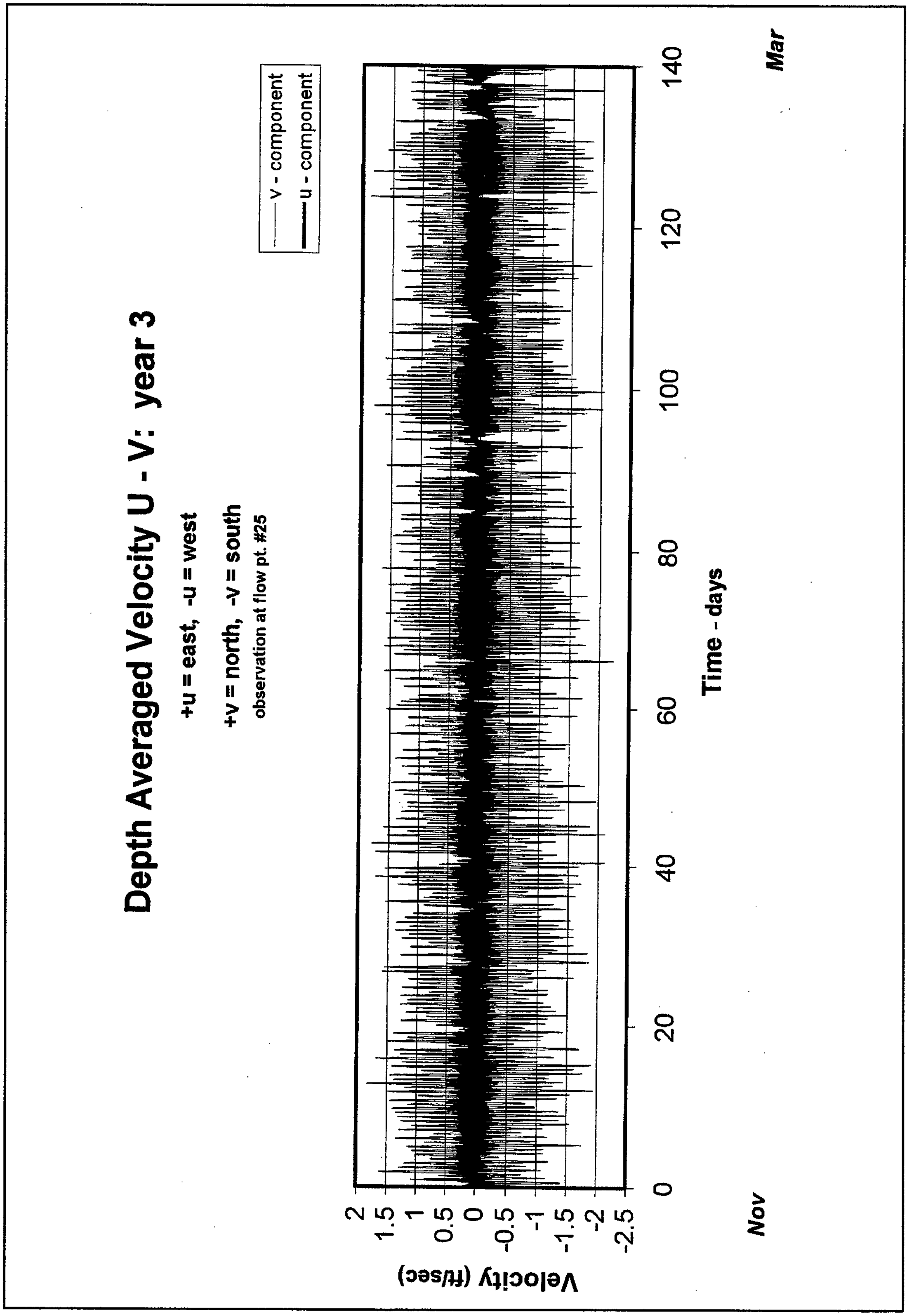

Figure 34. (Sheet 3 of 3)

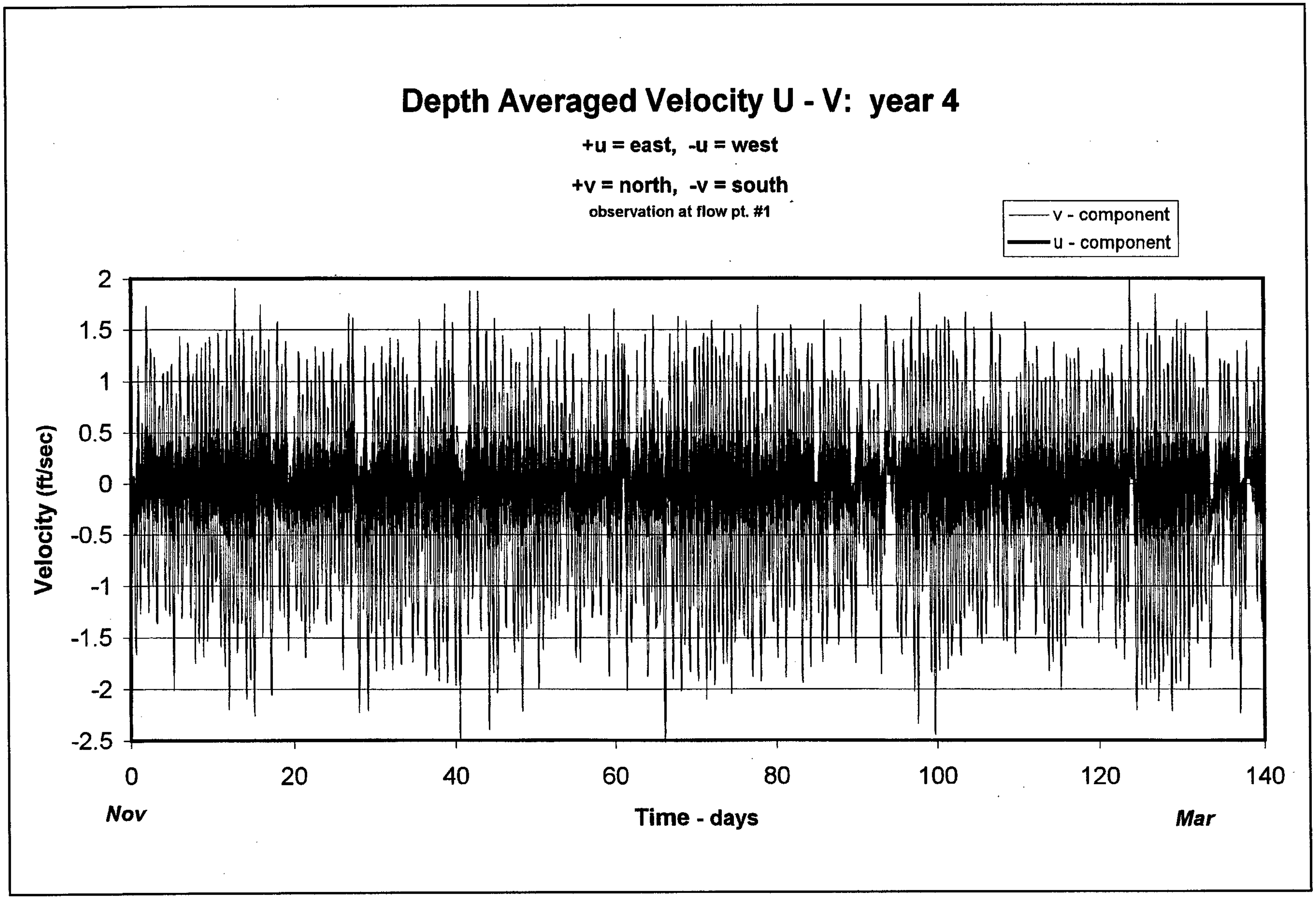

Figure 35. Vertically averaged velocity for Year 4 (Sheet 1 of 3)

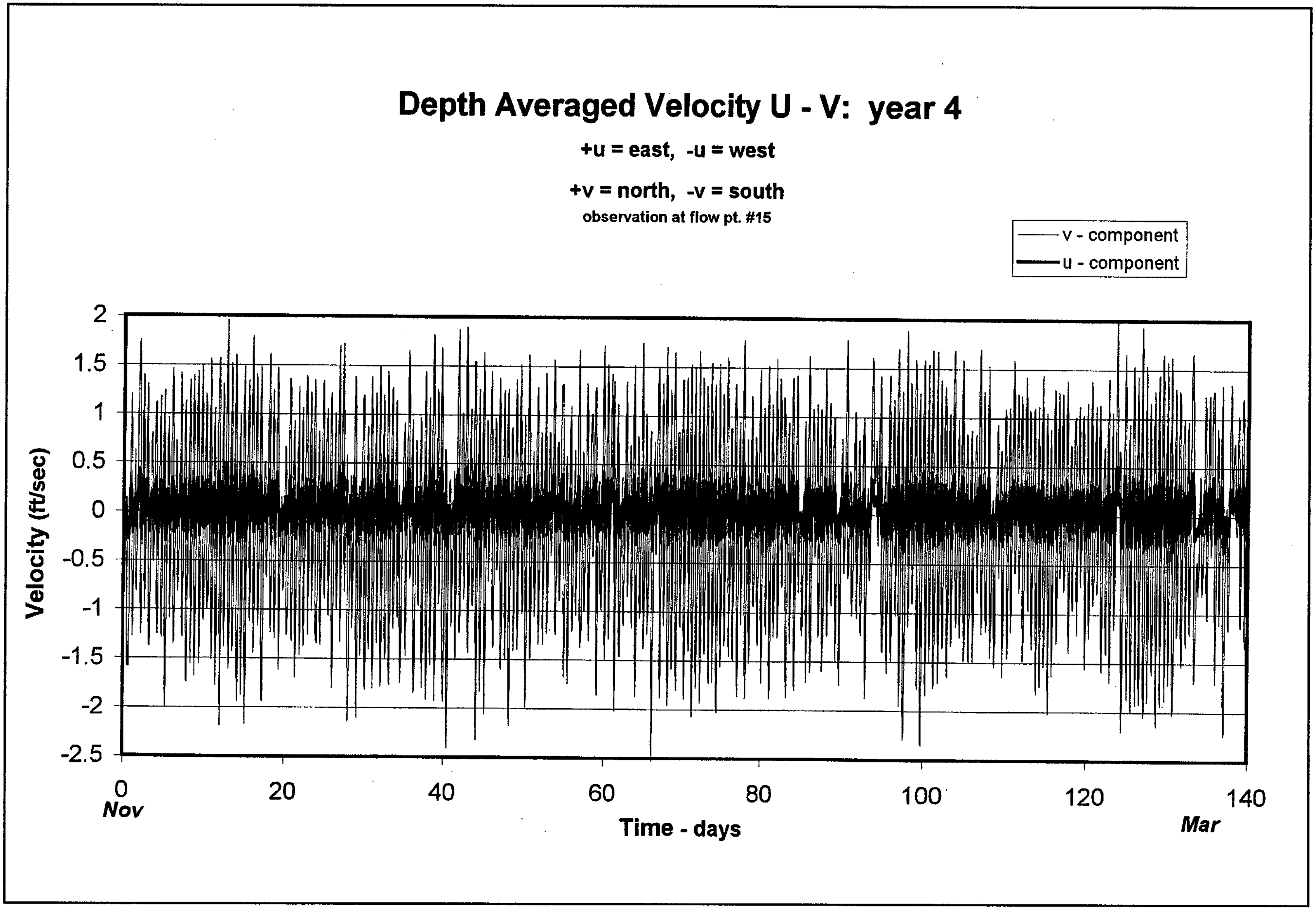

Figure 35. (Sheet 2 of 3)

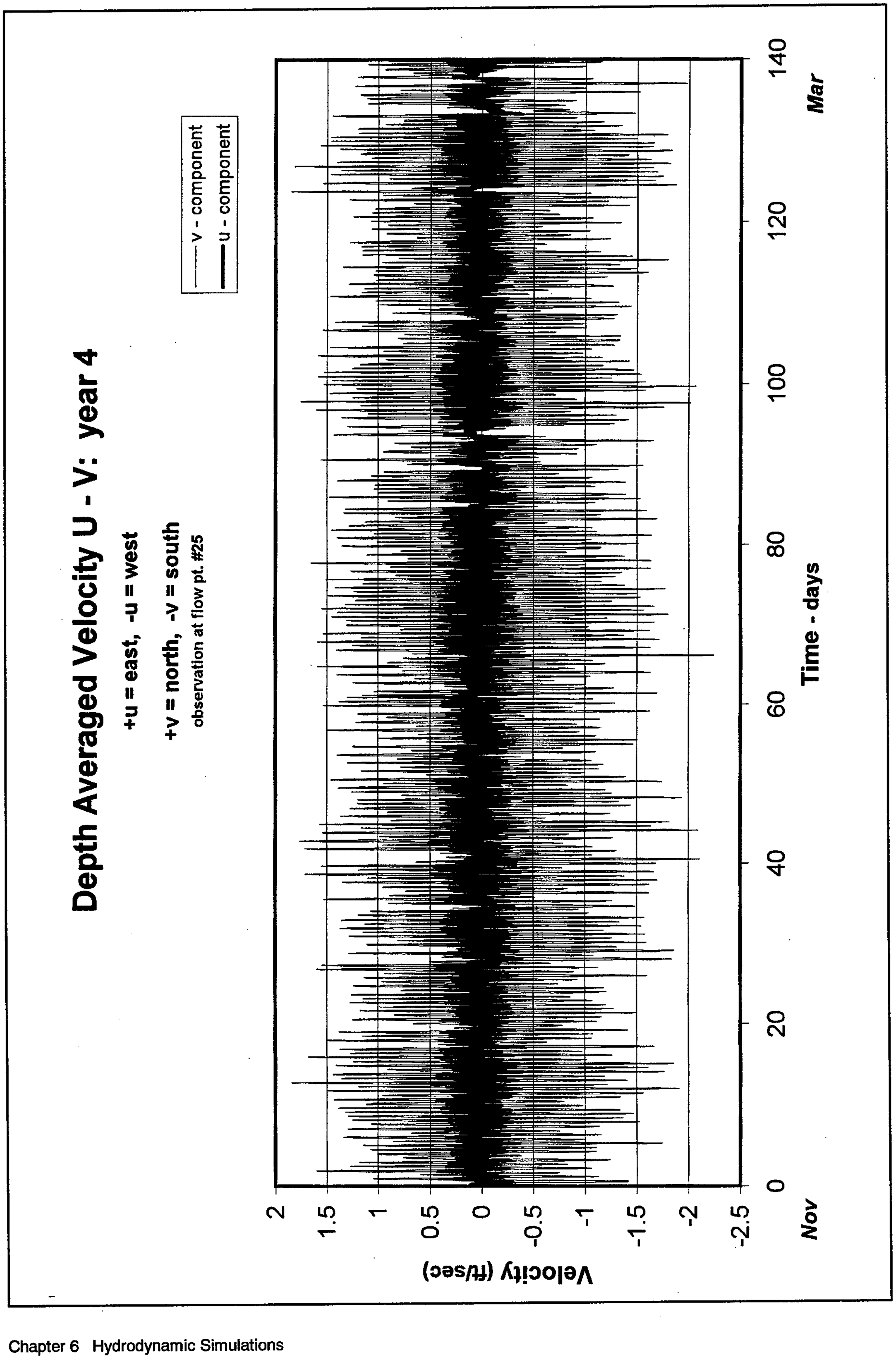

Figure 35. (Sheet 3 of 3)

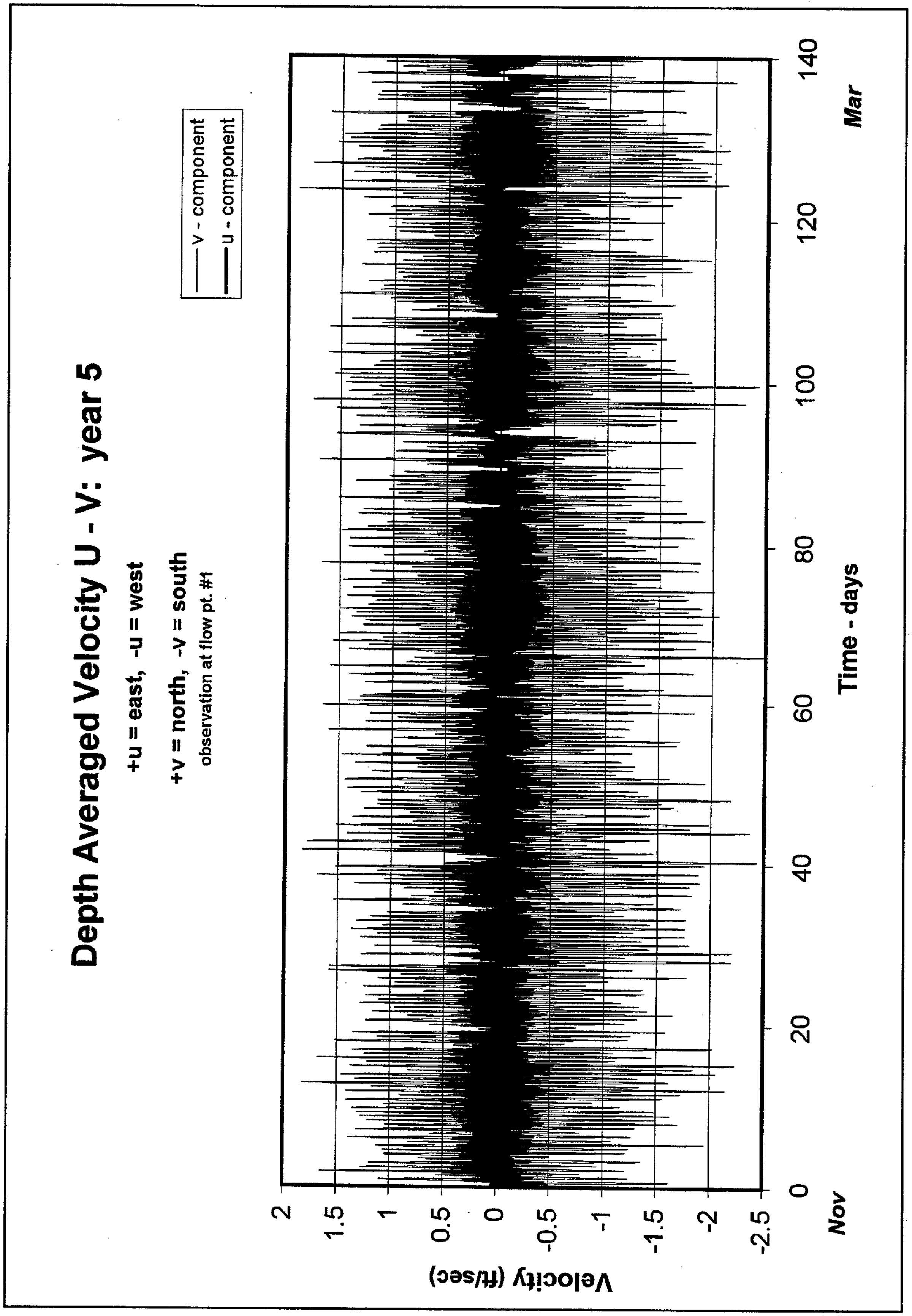

Figure 36. Vertically averaged velocity for Year 5 (Sheet 1 of 3)

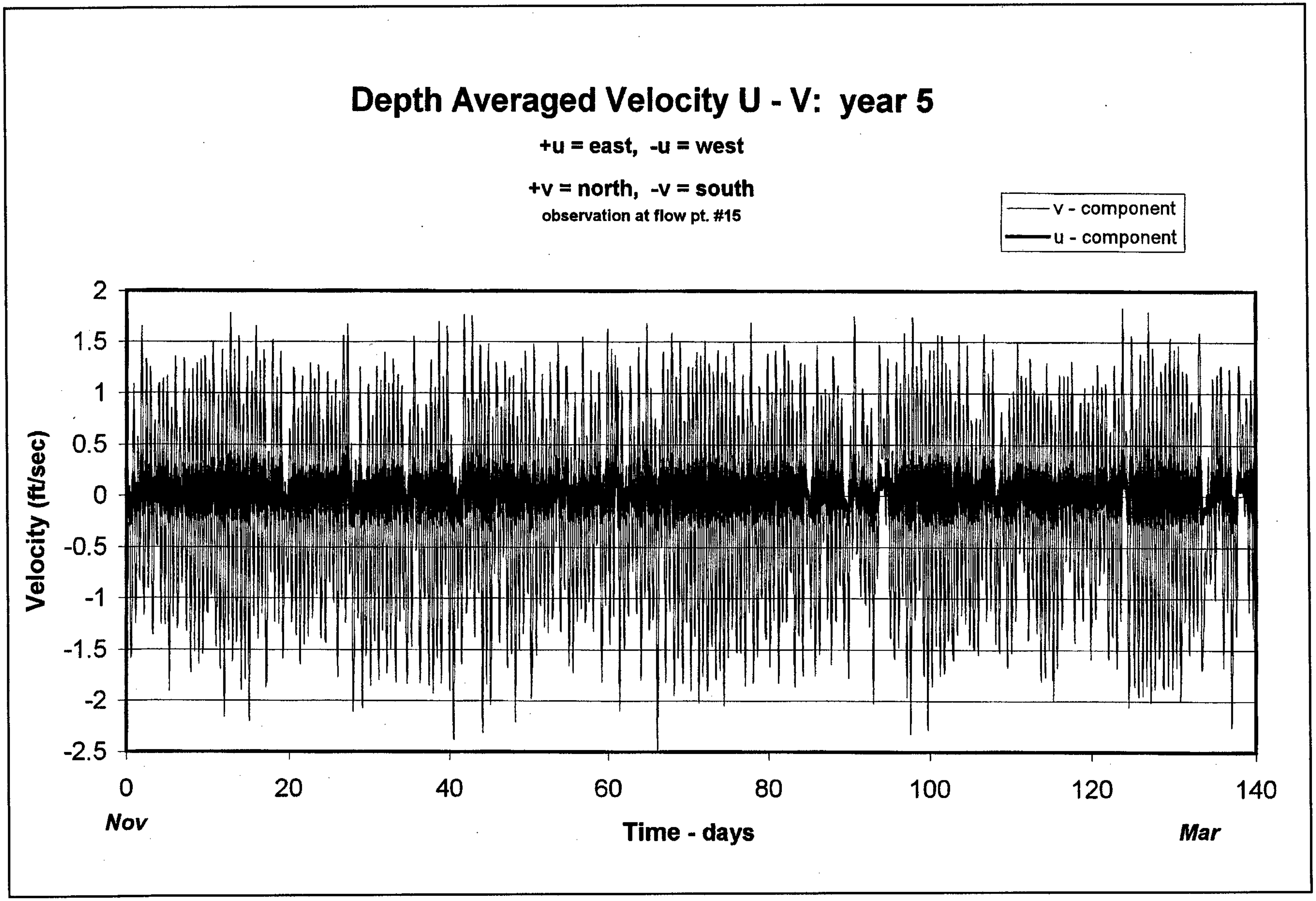

Figure 36. (Sheet 2 of 3)

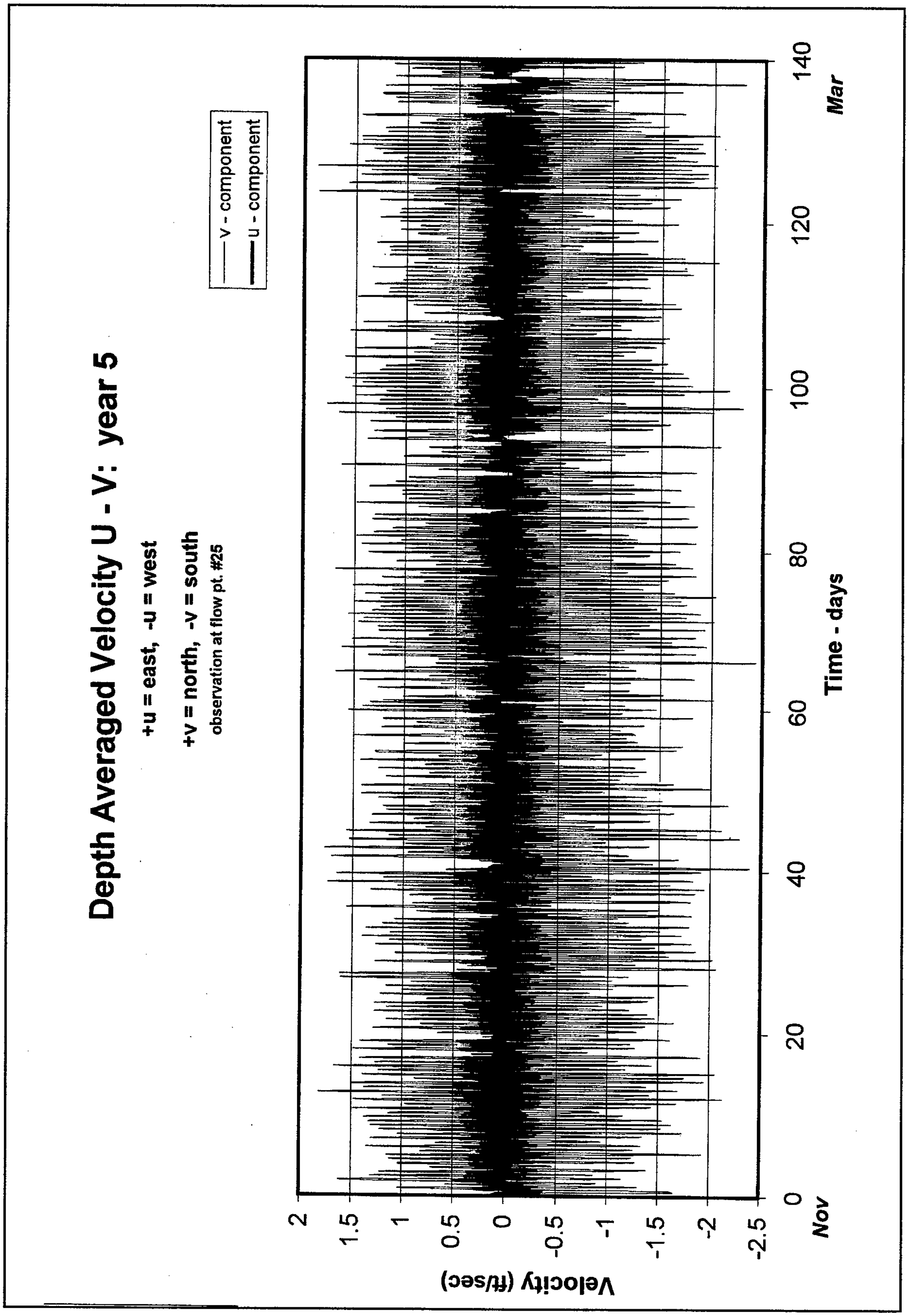

Figure 36. (Sheet 3 of 3)

7 STFATE and SURGE Simulations

Both the STFATE and SURGE models have been run at a few locations within Site 104 to provide insight on (a) the amount of material likely to be stripped away as the dredged material falls through the water column and (b) estimating the effect of bottom slope on the extent of the bottom surge resulting from a barge placement.

STFATE Results

Since the bottom is assumed to be flat in STFATE, these simulations were conducted assuming several constant water depths rather than inputting the actual bathymetry at the site. An inspection of Figures 7-11 (showing the locations of placements for each year), Figure 4, and five figures in the last section of Chapter 9 showing the site bathymetry reveals that placement at any particular time will occur in water depths varying from about 45 to 70 ft. Placements were simulated in these water depths at maximum ebb assuming a worst case vertically averaged velocity of 2.0 fps. Various input data required for operation of the model are given in Table 8. Operational data were provided by the Baltimore District, and the material characteristics were provided by the sediment tests previously discussed.

One should note that the total load of 3,600 cu yd is released as three separate loads of 1,200 cu yd each. This provides for a more accurate description of the bottom footprint of material deposited on the bottom from a moving barge.

Table 9 provides results from the STFATE simulations. One can see that even for the deepest placement location of 70 ft, less than 1 percent of the material is computed to be stripped during the convective descent of the dredged material cloud through the water column. This percentage agrees qualitatively with observations of Tavolaro (1984) and Truitt (1988). Model results indicate that because of the action of the ambient turbulence, very little of this fine suspended material will be deposited within the site, regardless of where the placement takes place.

Table 8
STFATE Input Data

Ambient Density	**Surface (1.01 g/cu cm)** **Bottom (1.02 g/cu cm)**
Ambient Vertically Averaged Velocity	2.0 ft/sec
Water Depth	45 to 70 ft
Barge Length	300 ft
Barge Width	50 ft
Loaded Draft	18 ft
Barge Speed	1.68 ft/sec
Time to Empty	60 sec
Number of Layers	**3 @ 1,200 cu yd ea**
Solids Concentration by Volume Clumps Silt Clay	 0.0079 cu ft/cu ft 0.0918 cu ft/cu ft 0.0918 cu ft/cu ft
Fluid Density	Surface 1.01 g/cu cm Bottom 1.02 g/cu cm

Table 9
STFATE Results

Water Depth, ft	Total Percent of Solids Stripped
45	0.27
50	0.38
55	0.47
60	0.56
65	0.65
70	0.73

Field data (e.g., suspended-sediment concentrations and depositional footprints from a single-placement operation) do not exist for verification of STFATE at Site 104. However, STFATE is a model routinely employed by the U.S. Army Corps of Engineers and the EPA to address water-column effects of open-water placement of dredged material. Verification of the model at various open-water site locations and to data collected in a large physical placement facility is discussed by Johnson (1978) and Johnson and Fong (1995).

SURGE Results

Surge requires output from a STFATE simulation. The information required consists of the bottom impact velocity, the density of the cloud, the size of the cloud at impact, and the amount of solids of each type contained within the cloud (Table 10). An inspection of Figures 7-11, Figure 4, and five figures in the last section of Chapter 9 illustrating the site bathymetry shows that placements might occur on bottom slopes of perhaps 0.01 to 0.015 ft/ft. The worst possible condition would occur for placements near the southern boundary. Thus, the water depths for STFATE simulations to provide SURGE input and the slopes assumed are representative of worst case placement conditions near the southern boundary.

Table 10
SURGE Input

Run	Water Depth, ft	Slope ft/ft	Bottom Cloud Information			Clay cu ft	Silt cu ft	Clumps cu ft
			Vel, fps	Radius ft	Density g/cu cm			
1	50	0.015	7.823	31.23	1.14720	2,964	1,886	256
2	65	0.010	6.495	38.59	1.08634	2,955	1,880	256
3	70	0.015	6.109	41.06	1.07468	2,952	1,878	256

Results are provided in Table 11 showing the predicted extent of the surge for placements with and without a bottom slope. It can be seen that bottom slope has a significant impact on bottom surges containing fine-grained material. These results were obtained assuming a constant bottom downslope. To investigate the impact of an upslope, Run 3 was rerun with the placement occurring 1,000 ft in front of a 20-ft-high mound with an angle of repose of 8 deg. SURGE predicts that the bottom surge will stop without overtopping the mound.

Table 11
SURGE Results

Run	Water Depth, ft	Slope	Predicted Extent of Bottom Surge, ft
1	50	0.0 0.015	720 2,230
2	65	0.0 0.010	920 1,700
3	70	0.0 0.015	980 3,020

The results from SURGE should be viewed with a certain amount of caution. Data on the extent of a surge resulting from a single-placement operation do not exist at Site 104 for verification of the model. In addition, one should remember that results are very dependent on parameters such as the rate of dissipation and the rate of conversion of potential energy to kinetic energy. Values for these parameters were taken from Bokuniewicz et al. (1978). However, with these values, Clausner et al. (1998) determined that SURGE was able to predict the extent of the apron (deposition depths of 1-2 cm) at the New York Mud Dump Site.

Results from SURGE were not used in the MDFATE modeling. SURGE runs were made purely to provide insight into the impact of bottom slopes on the movement of fine-grained turbidity clouds.

8 Generation of Hydraulic Placement Footprint

The hydraulic placement mound thickness and diameter were estimated through a joint effort by Moffatt & Nichol Engineers and WES, based on previous work by Thevenot, Prickett, and Kraus (1992). Assuming that the discharge pipe is near the bottom (within six pipe diameters) to minimize losses to the water column, the analysis focused on processes affecting the spreading of the underflow. The actual discharge should be from a stationary vertical pipe with a diffuser to reduce the velocity of the material exiting the pipe.

The thickness and rate of spreading of the underflow depend on plume conditions at the point of bottom encounter, topography of the bed, ambient flow, and viscosity and settling of the underflow material. Cohesive dredged sediment viscosity (at low shear rates) increases with concentration to about 1 to 5 Pa-sec (or about 1,000 to 5,000 times the viscosity of water) as the sediment approaches a transition state where it develops a space-filling structure (about 125 g/L). The sediment will continue to settle and consolidate to higher densities at a very slow rate, and the corresponding viscosities then climb rapidly to 10s and 100s of Pa-sec. Viscous effects are important at underflow concentrations of about 50 g/L or greater.

Spreading of a fixed-volume underflow was considered analytically in this study. The assumptions were that the bottom is horizontal, viscosity is constant, the overlying flow exerts negligible shear stress on the underflow, and the spreading is radially outward from the location where the discharge jet impinges on the bottom. Underflow spreading was evaluated assuming that the underflow is laminar and that the viscosity is much greater than water, but low enough so that material will have an approximately level top surface. Laminar conditions occur when the Reynold's Number for the spreading layer has a value of no more than a few hundred. These values are typical of conditions a short distance from the placement point.

Spreading and shear-stress dissipation are driven by pressure caused by the density difference between the underflow and the ambient. The pressure at the edge of the underflow varies with distance from the bed and averages $g(\rho_m - \rho_o)h/2$. The total force F_r acting on the area of the edge is:

$$F_r = \pi g\ (\rho_m - \rho_o)\ Rh^2 \tag{6}$$

where

ρ_m = underflow density

ρ_o = ambient density

R = total radius of underflow

h = underflow thickness

The underflow shear stress depends on underflow flow speed $U_u(r)$ and, therefore, varies along the radius r of an expanding underflow layer. Because the underflow is assumed laminar, local shear can be calculated as 2 $U_u(r)/h$. For a constant volume underflow, the area-weighted average shear stress occurs at 0.79 U_u, exerting a total force F_t over the bottom of the underflow as:

$$F_t = 1.59\pi\eta\ \frac{U_u\ R^2}{h} \tag{7}$$

where η is the low-shear viscosity. Thus, the spreading rate of a slug of material volume V can be estimated by substituting $R = (V/\pi h)^{1/2}$ to give:

$$U_u = \frac{1.1g\ (\rho_m - \rho_0)\ h^{7/2}}{\eta V^{1/2}} \tag{8}$$

where V is the pump out volume. According to this analysis, the underflow will continue to spread at decreasing speeds because the processes that might halt spreading, such as settling and gelling, are not included.

For this case where underflow spreading occurs while also undergoing consolidation, the following equation was used to increase the density of the placed material:

$$\rho_m = \frac{Cv}{(h-W_s\ t)/h} + \rho_o \tag{9}$$

where

Cv = solids volume concentration

h = underflow thickness

W_s = settling velocity of material

t = time

Equation 9 reflects settling increases in characteristic underflow concentration through consolidation. As concentrations of cohesive suspensions increase, a concentration is reached where settling velocities become hindered by interparticle contact. At slightly higher concentrations, settling fluxes (the product of settling speed and concentration) also begin to decrease. At these higher concentrations, suspensions settle as a mass and form a distinct layer. Settling in the hindered settling concentration range can be approximated by:

$$W_s = W_i\,(1 - kC)^5 \tag{10}$$

where

W_i = maximum settling speed

k = inverse of fully settled concentration, about 0.002 L/g

C = underflow concentration, g/L

W_s rapidly decreases with concentration in the dense suspension-concentration range for cohesive sediments. Because W_s decreases with concentration, progressively longer times are required to settle and consolidate for progressively higher concentrations.

The computation for the hydraulic placement footprint input to MDFATE used a constant fixed-volume underflow since the assumption was that a fixed barge volume of material will be pumped out for each placement. With the parameters presented in Table 12, the computations produced footprint radii ranging from 367 to 433 ft and thicknesses ranging from 0.2788 to 0.3805 ft. The selected footprint for input to MDFATE initially had a radius of 423 ft and a thickness of 0.3805 ft. However, the volume (after settling) of this footprint was 7,940 cu yd; whereas, if all of the solids transported to the site and placed by a barge or scow were to be deposited at the assumed bulk voids ratio of 8.4 (See Chapter 9, MDFATE Simulations, MDFATE Consolidation Calculations for Site 104), the depositional volume would be 5,363 cu yd. This volume is determined from the 3,600 cu yd of dredged material in the barge multiplied by the solids volume concentration of 0.1594 multiplied by the factor (1 + bulk voids ratio). Thus, the final thickness employed for the hydraulic placement footprint was adjusted to 0.2558 ft to yield the same depositional volume of solids as would occur with the barge placement.

Table 12
Parameters Employed in Computing Hydraulic Placement Footprint

Average Moisture Content	66.8%
Solids Volume Concentration	0.1594 cu m/cu m
Solids Concentration	422 dry kg/cu m
Bulk Wet Density	1.27 g/cu cm
Measured Liquid Density	1.01084 g/cu cm
Solid Density	2.65 g/cu cm
Underflow Concentration at Bottom	125 kg/cu m
Underflow *Cv* at Bottom	0.04716 cu m/ cu m
Underflow BWD at Bottom	1.0882 g/cu cm
Volume per Barge	9,237 cu m
Bulking Factor	3.38
Low-Shear Dynamic Viscosity	5 Pa-sec
Settling Rage W_i	0.00001 m/sec

The volume to be pumped out was determined by assuming that the material would be slurried to yield a concentration of 125 g/L. Typical pump out concentrations from pipelines range from about 100-200 g/L, e.g., the concentration pumped at Tylers Beach (Thevenot, Prickett, and Kraus 1992) was 154 g/L. The bulking factor, defined as the pumped volume divided by the volume in the barge, is dependent on the assumed concentration. Thus, the value at Tylers Beach would have been slightly lower than the value of 3.38 computed here. If a 24-in.-diam pipe were used, this volume could be pumped in about 30 min. The spreading using the approach outlined above lasts about 9,000 sec. Since the spreading lasts much longer than the time for pump out, the assumption that the entire volume is instantaneously available to drive the spreading is reasonable. Sensitivity computations using different bottom radii and heights revealed that the computed footprint was insensitive to the shape of the initial volume of material.

9 MDFATE Simulations

Reliability of MDFATE Application at Site 104

Typically, the performance of a bathymetric change model such as MDFATE is assessed (verified) at a given location before a production run is made. Model verification consists of using MDFATE to hindcast a previous placement operation. The data needed for hindcasting consist of prebathymetric and post-bathymetric surveys of the placement site, adequate description of the actual placement operations, and a quantification of the placement site wave and current regime. For more information on verifying the MDFATE model, one should refer to Moritz and Randall (1995). No recent placement data were available at Site 104 for verifying MDFATE computations. However, MDFATE has been applied for several placement operations in the past with good results. An example is the work by Lillycrop and Clausner (1997) on the design of a capping project at the New York Mud Dump Site. Hindcast data available from the placement of 585,000 cu yd of material compared well with MDFATE results. The maximum hindcast and actual mound heights were approximately 10 and 8 ft, respectively. However, although ambient currents and water depths at Site 104 are similar to those at the New York Site, the wave climate at the Mud Dump Site is more severe than that at Site 104. Other examples of successful MDFATE application are available in Moritz and Randall (1995), U.S. Army Corps of Engineers (USACE) (1995, 1997), and Clausner, Gailani, and Allison (1998). The accuracy of MDFATE results is highly dependent upon the parameters input to the model. Controlling parameters are physical characteristics of the dredged material, placement-operation sequencing, and forcing environment. As discussed in Chapters 4, 5, and 6 of this report, much effort was expended to develop reliable input for the MDFATE model.

Discretization of Site 104

The extent of Site 104 used for simulation of dredged material placement included the southernmost 16,000 ft (70 percent) of the site. The total (N-S) length of Site 104 is about 22,000 ft, and the total (E-W) width of Site 104 is about 3,800 ft. The total areal extent (domain) modeled by MDFATE was 19,000 ft in the North-South direction and 7,800 ft in the East-West direction.

Thus, the MDFATE domain for this simulation included a 2,000-ft margin on each side of the site's E-W boundaries and a 3,000-ft margin on the site's southern boundary to ensure the capture of all material placed. A uniform 100-ft grid interval was used to discretize the Site 104 area of interest. This produced a 14898 element grid for the MDFATE domain. The entire MDFATE Site 104 domain covers approximately 3,400 acres.

Coordinate geometry for the Site 104 MDFATE domain was based on the Maryland state plane system NAD 83 (ft). Vertical datum was MLLW (ft). Bathymetry for the MDFATE domain was developed from a composite of USACE surveys (taken during 1996 and 1997) and NOAA data. The overall boundaries of the Site 104 domain used in the MDFATE simulation are summarized below.

MDFATE Site 104 domain: 19,000 by 7,800 ft, azimuth of the site's principal axis = 17°, variation of bottom elevation = -10 ft MLLW to -95 MLLW. Corner coordinates (MD, NAD 83) are given as:

Northwest Corner	- Easting = 1495333 ft,	Northing = 500500 ft
Northeast Corner	- Easting = 1502761 ft,	Northing = 498285 ft
Southwest Corner	- Easting = 1489809 ft,	Northing = 482285 ft
Southeast Corner	- Easting = 1497238 ft,	Northing = 480000 ft

The configuration of the MDFATE domain used in this analysis, along with the formal boundaries of Site 104, is shown in Figure 4. One should realize that when the contours shown in Figure 4 were created, an isolated depth such as -95 ft was averaged out. In addition, although the -25-ft contour is the most shallow one shown, depths as low as -10 ft exist. Also, one should note that Figure 4 does not show the northern portion of Site 104.

Sequencing and Distribution of Dredged Material Placement

During the 5 placement years of interest, the placement of dredged material was simulated to occur between 1 November and into March, after which only bottom-sediment erosion and consolidation processes were simulated. The duration of each MDFATE simulation is 1 year, performed sequentially for the 5 years of interest. The volume of dredged material to be placed per year for the MDFATE simulation varied from 2.5 to 6.0 million cu yd. Table 1 summarizes dredged material placement quantities and timing for each of the 5 years simulated. The caption shown below describes the annual MDFATE sequencing of dredged material placement and sediment erosion and consolidation simulations for the Site 104 study.

Placement Simulate Placement Season Fate Only	Simulate Remaining Part of the Year: Long-Term Fate Only
(1) Model a series of 1-week dump episodes for short-term fate processes (2) Follow-on with long-term fate calculations for 1 week after each dump episode	Model bathymetric change because of erosion and consolidation
November varied 112-168 days March	varied 196-252 days October

Modeling of the Annual Dredged Material Placement Cycle at Site 104.

To ensure that the 18 million cu yd of proposed dredged material matches the site capacity, with the buffer zones discussed below excluded as areas for placement, a working vertical limit of -42 ft MLW was adopted in the MDFATE modeling. The total volume of dredged material placement capacity (storage) within Site 104 below -42 ft MLLW was calculated by subtracting the existing bathymetry within the Site 104 boundary from a "glass ceiling" positioned at -42 ft MLLW. In other words, the available storage is that volume below where a horizontal plane located at -42 ft MLLW intersects the site bathymetry. The placement capacity resulting from the above calculation was 23 million cu yd with the buffer zones included but only 18 million cu yd with the buffer zones excluded. Figure 37 shows the existing capacity available within Site 104, in terms of vertical clearance below -42 ft MLLW. If a vertical limit of -45 ft MLLW had been adopted to limit the vertical accumulation of dredged material placed in Site 104, the resultant Site 104 placement capacity would have been 18 million cu yd with the buffer zones included but only 14 million cu yd with the buffer zones excluded. As discussed below, accounting for a buffer zone around Site 104 minimizes the possible loss of material from the site during the placement operation. The above site capacity estimates do not include the area of Site 104 north of the MDFATE domain limits. This area accounts for about 20 percent of the total areal limits of Site 104 but possesses relatively shallow-water depths. The additional capacity available within this area was estimated to be about 1 million cu yd for the -42 ft MLLW vertical limit and 0.3 million cu yd for the -45 ft MLLW limit.

The proposed project calls for a vertical limit of -45 ft. From the site capacity computations discussed above, extreme care in developing a placement plan will be required to meet this without allowing excessive material to leave the site during placement. The time frame for the MDFATE modeling presented herein did not allow for repetitive runs each year to fine tune the placement plan. Thus, buffers were set up within the site near its boundaries to minimize material lost during placement. This resulted in a vertical limit of -42 ft being selected to yield a site capacity of 18 million cu yd.

Strategy for Utilizing the Site 104 Capacity

During the initial phase of this study, the strategy for assigning placement locations within Site 104 was intended to confine placed dredged material within the longitudinal depression of Site 104. It was assumed that placing dredged

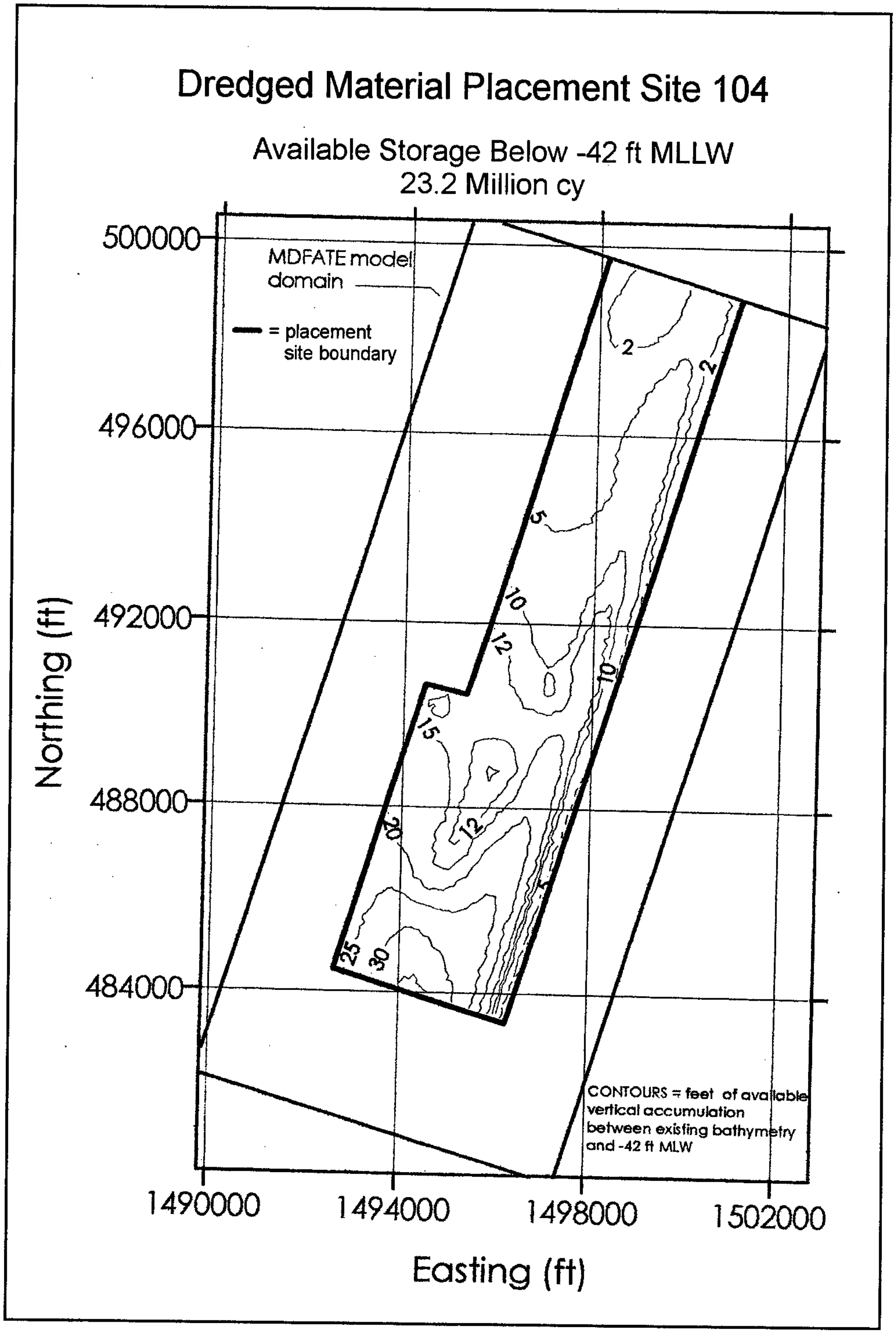

Figure 37. Initial capacity of Site 104 below -42 ft MLLW

material in the deeper areas of Site 104 would provide for enhanced material impoundment. Based on preliminary MDFATE results, this method of placement resulted in excessive vertical accumulation of placed dredged material (above -35 ft MLLW). The original placement-control plan (assignment of placement locations) was modified to reduce vertical accumulation of dredged material placed within Site 104. (See Chapter 4, Placement Schedules).

The spatially modified placement plan also addressed the need to minimize the areal extent (surface area) of the placement footprint on a per year basis to prevent excessive long-term erosion of accumulated dredged material. To meet these mutually incompatible objectives, a placement grid was developed to promote uniform distribution of dredged material placed in Site 104 while ensuring that the entire available area is utilized (in terms of the MDFATE domain). The placement-control plan (grid) used to simulate dredged material placement in Site 104 is shown in Figure 5. As previously discussed, each symbol in Figure 5 represents the centroid of a 300- by 500-ft cell. There are a total of 240 cells within the boundary of Site 104 used for assigning individual locations for this simulation. The placement cells are intended to only assign the beginning point for a given placement. The entire placement need not be confined to the assigned cell. The "triangular" points indicate shallow-water placement cells (bottom elevation <55 ft MLLW), and "crosses" indicate deep- water placement cells.

As previously noted, there is a 500-ft buffer zone along the E-W sides of Site 104 and a 1,200-ft buffer at the southern end of the site that are contained within the site. The intent of the buffer is to ensure that placed dredged material is not transported beyond the formal Site 104 boundary during placement operations. The buffer dimensions were developed based on insight obtained from preliminary STFATE simulations. Accounting for the presence of a buffer at the perimeter of the Site 104 boundaries, the full 23 million cu yd placement capacity (based on -42 MLLW) for the site is reduced to 18 million cu yd. As previously noted, this is the volume of dredged material expected to be placed within Site 104 for the 5-year study time line. The management challenge for Site 104 is to achieve optimum utilization of the site's capacity without unnecessarily increasing the surface area of the placement footprint and incurring increased erosion loss of placed material. As discussed in Chapter 4, to meet this site management challenge, a "modified placement plan" was used to simulate dredged material placement in Site 104. The term "modified placement plan" refers to the fact that for each year the placement plan must be "modified" to account for changing site-capacity constraints.

To illustrate the need for careful selection of a "modified placement plan" at Site 104, long-term fate results obtained using two different placement distributions for Year 1 (placement of 2.5 million cu yd) are compared in terms of mass loss because of erosion. A "uniform spreading" placement method (placement locations shown in Figure 6) resulted in the wide distribution of placed dredged material shown in Figure 38. A "modified placement plan" with controlled placement (placement points shown in Figure 7) resulted in the more confined and peaked distribution of placed dredged material shown in Figure 39. Figure 40 shows the long-term mass loss for each placement method for Year 1.

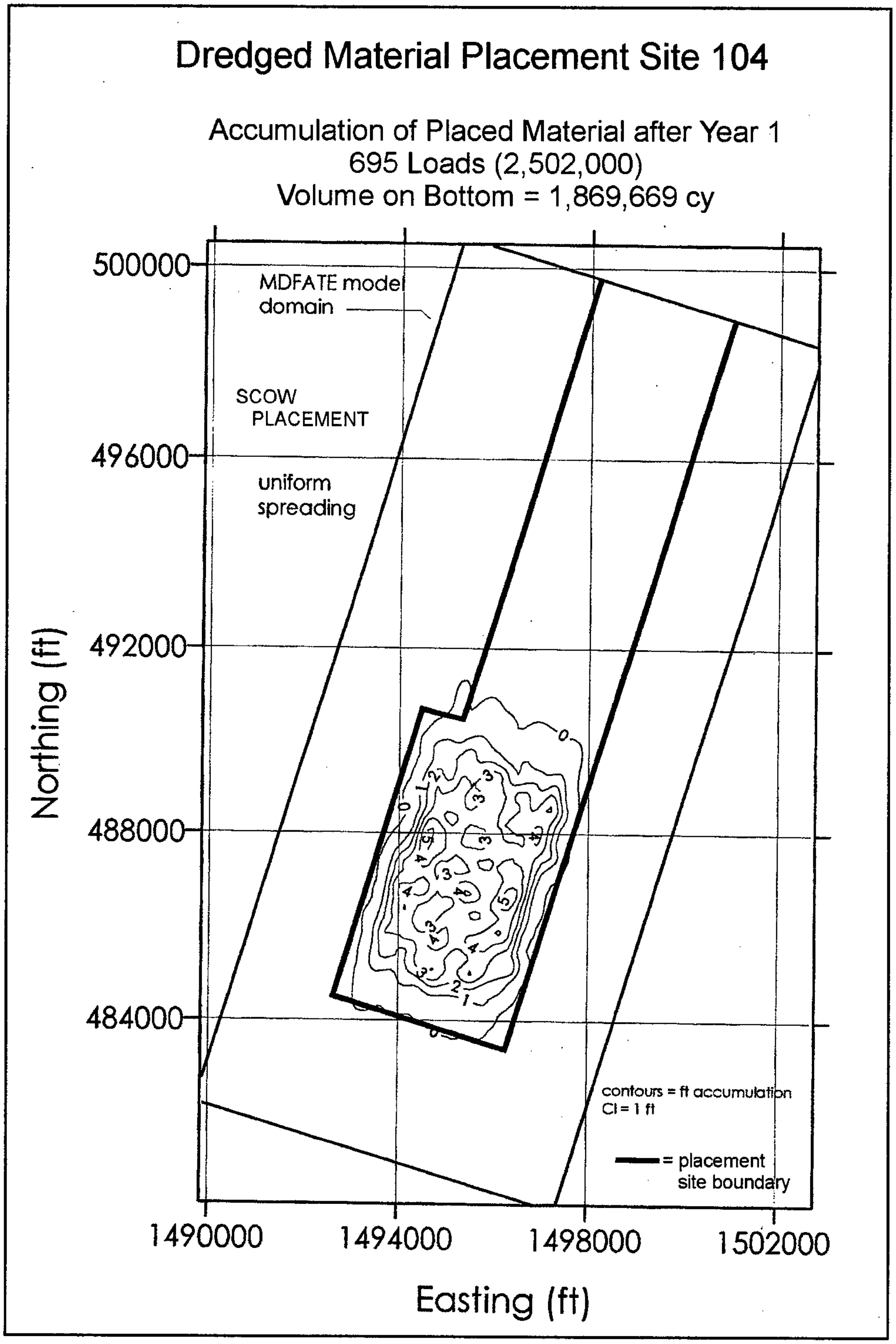

Figure 38. Cumulative deposition contours for uniform placement plan after Year 1 with barge placement

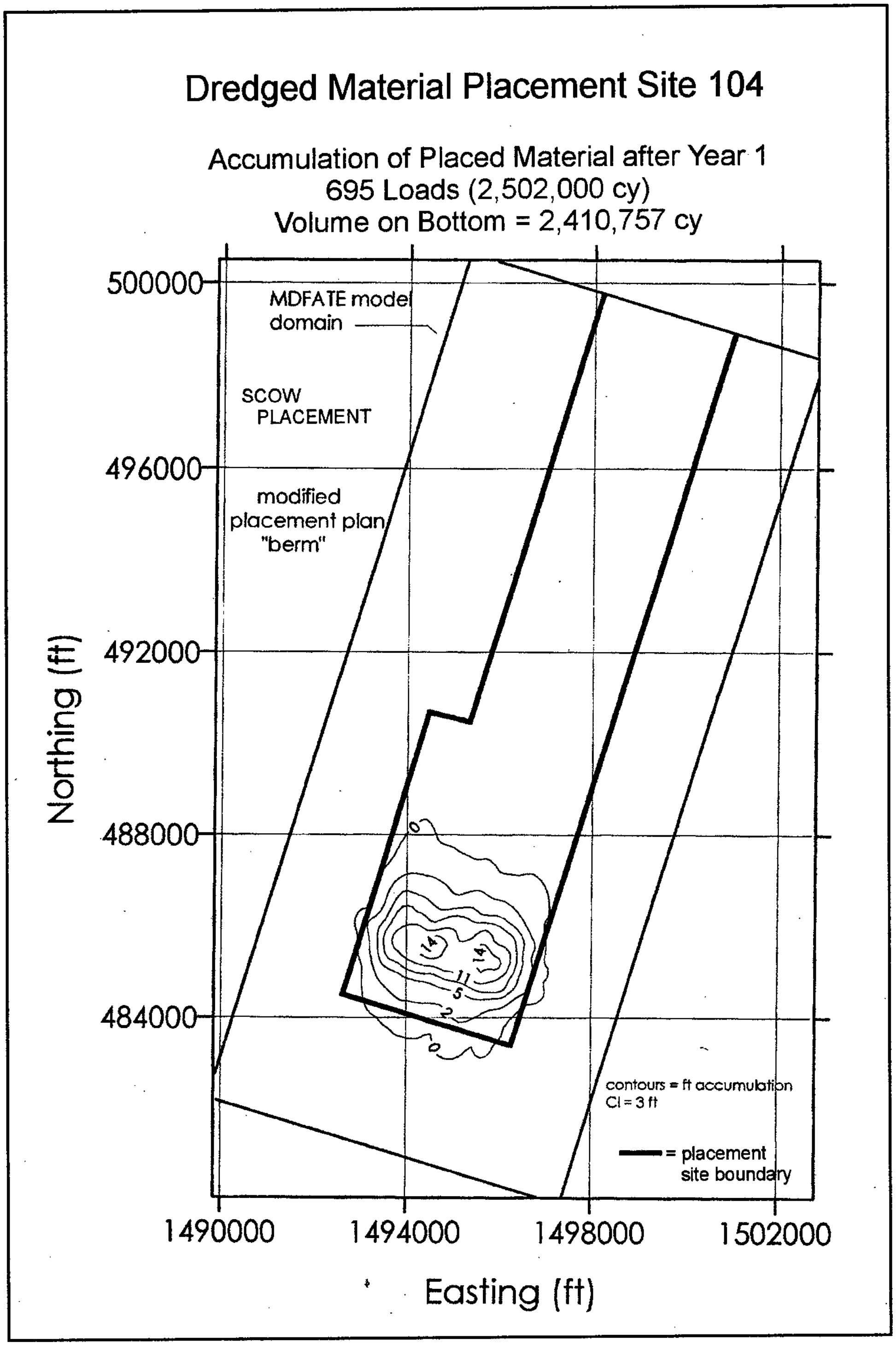

Figure 39. Cumulative deposition contours for modified placement plan after Year 1 with barge placement

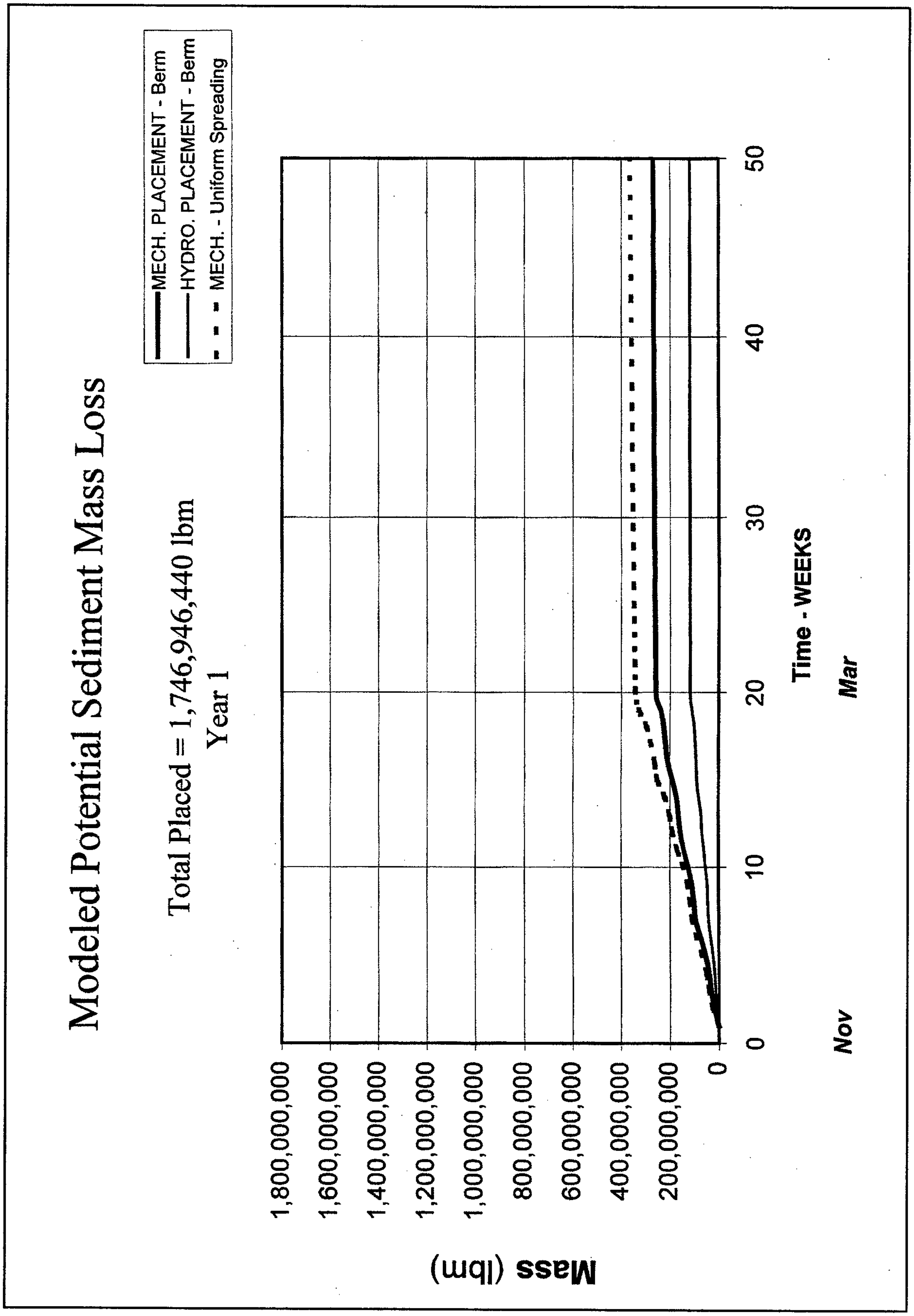

Figure 40. Cumulative deposited mass eroded for Year 1

Both barge (mechanical) and hydraulic discharge methods were used for the "modified placement" option. Only the barge discharge method was used for the "uniform spreading" placement option. One should note the significantly higher mass loss for the "uniform spreading" placement plan as compared with the "modified" option. The higher mass loss (30 percent more) for the "uniform spreading" is due to the increased surface area of the "uniform plan" and was deemed unacceptable.

Based upon the lower predicted erosion of placed material, the "modified placement plan" appears to be the best method for utilizing available placement capacity within Site 104.

Annual Assignment of Placement Areas

The 240 available placement cells shown in Figure 5 were used to assign the coverage and density of placements made during Years 1-5. To assign placement points for a given year, the cell centroids were overlaid on the updated site-capacity map (Figure 37 shows available capacity for Year 1). Target areas within Site 104 were selected based on the volume of dredged material to be placed and the distribution of available site capacity. Available site capacity (below -42 ft MLLW) for placement Years 2-5 is shown in Figures 41-44. After the target area is selected, the number of placements per cell is assigned based on allowable vertical accumulation at each cell within the target area. The number of loads that can be placed within a given cell without exceeding the allowable vertical accumulation is a function of the placement-mound geometry (per placement). A tabulation of estimated mound geometry (per placement) for various water depths is given below in Table 13. These results were obtained using the STFATE model assuming a flat bottom. Actual mound geometry at Site 104 will be different because of material "collecting" in bottom depressions or being affected by slope. The maximum thickness per placement (for the 1-ft/sec bottom current—see Figures 20 and 21) was used to determine the number of placements per cell that could be placed within the selected target areas.

Table 13
Estimated Dredged Material Deposition Geometry per Placement (Based on STFATE)

	No Current			Bottom Current = 1 ft/sec		
Water Depth, ft	Max. Thick, ft	Length, ft	Width, ft	Max. Thick, ft	Length, ft	Width, ft
40	3.2	700	600	1.8	1,600	500
50	2.5	800	700	1.4	1,600	700
70	1.2	1,000	1,000	0.8	1,600	900

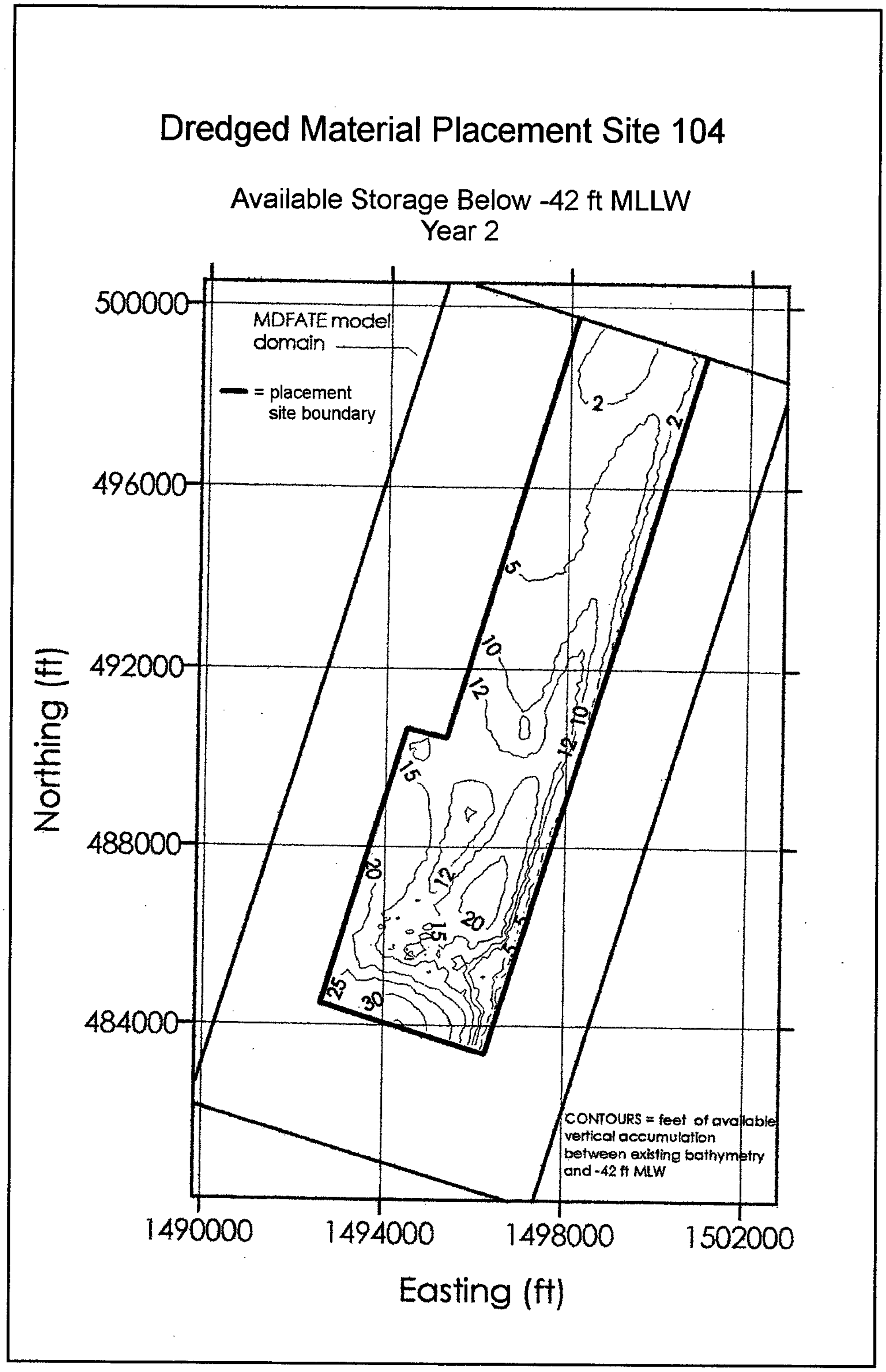

Figure 41. Capacity of Site 104 below -42 ft MLLW after Year 1

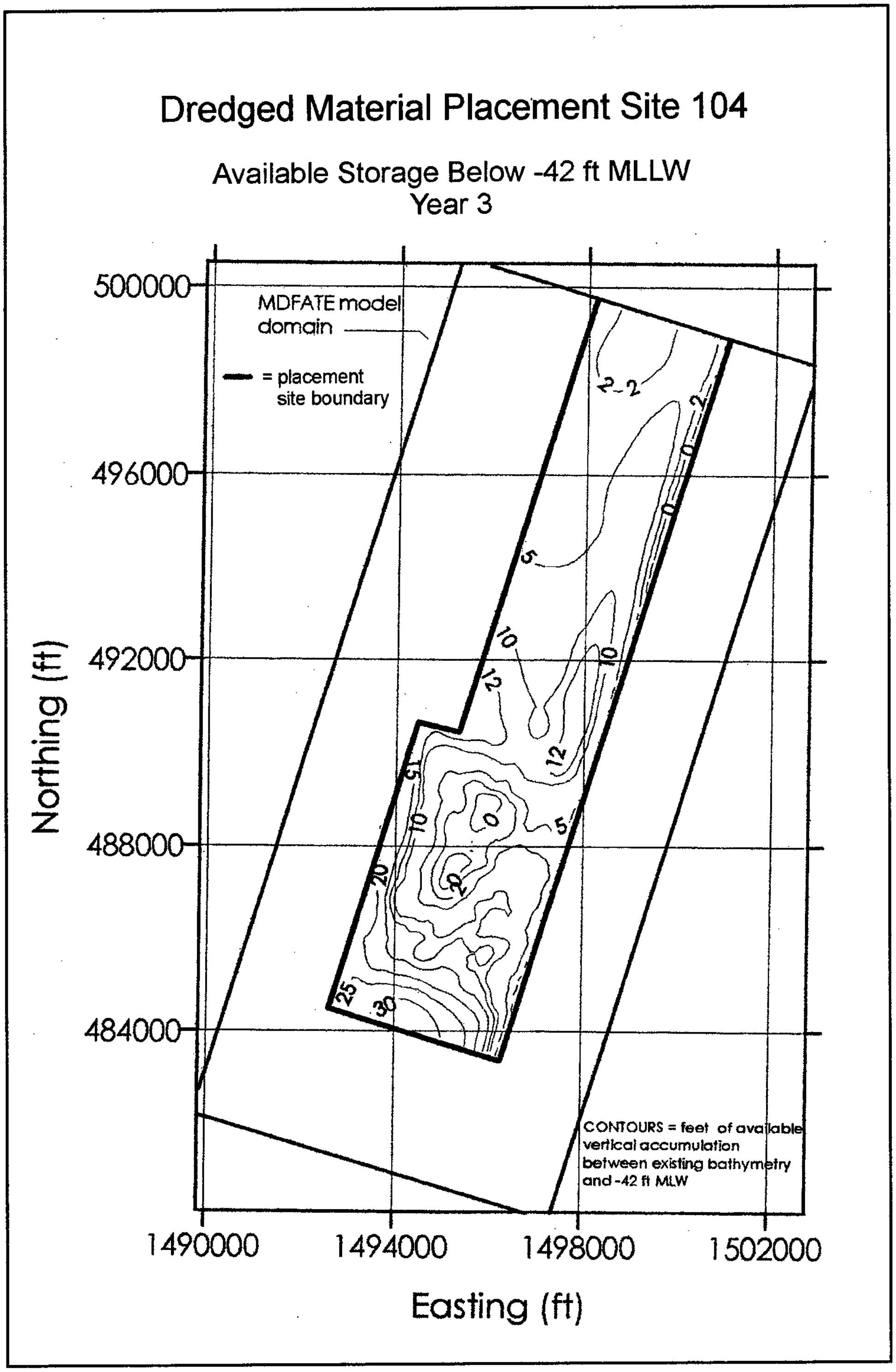

Figure 42. Capacity of Site 104 below -42 ft MLLW after Year 2

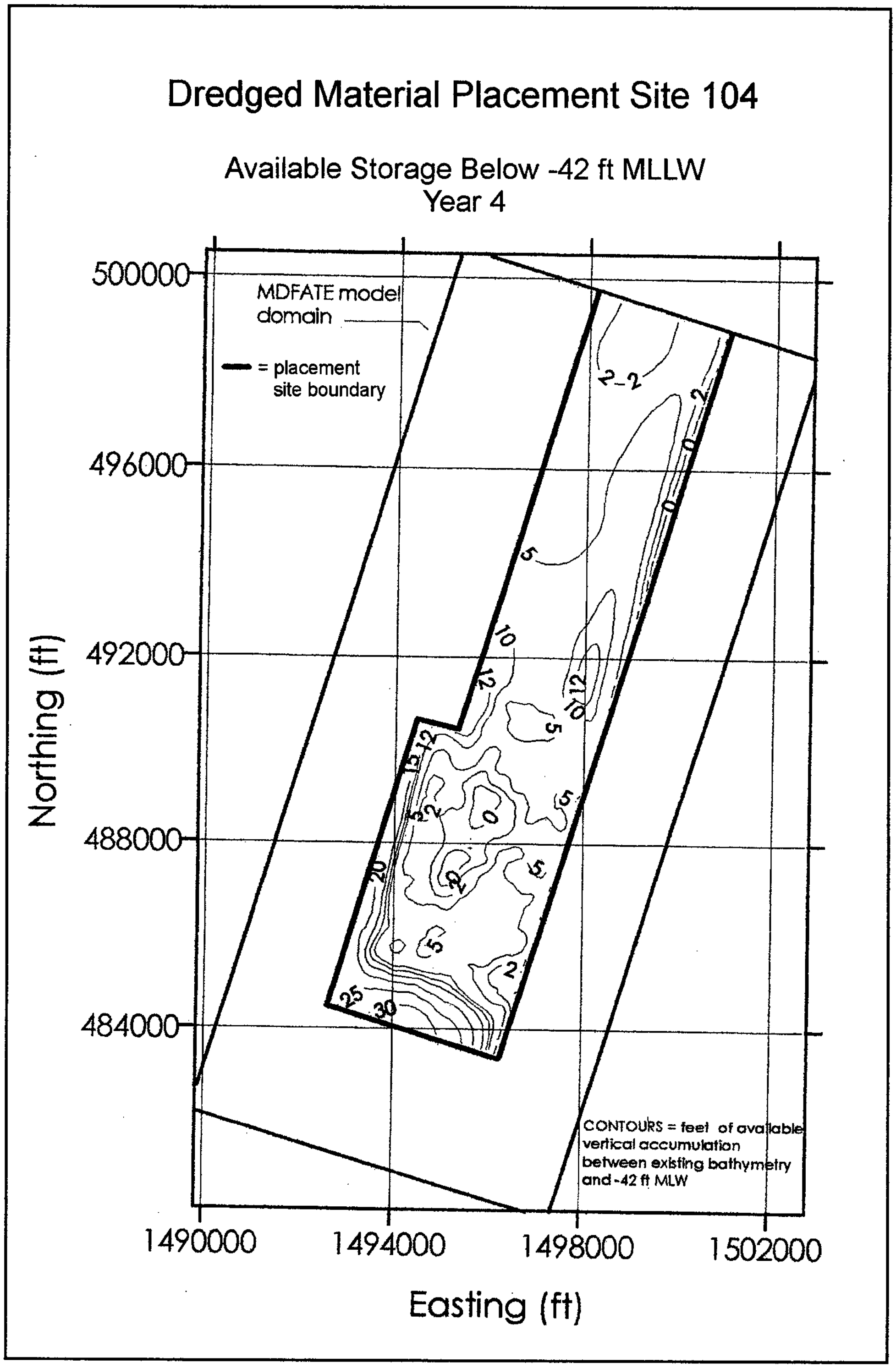

Figure 43. Capacity of Site 104 below -42 ft MLLW after Year 3

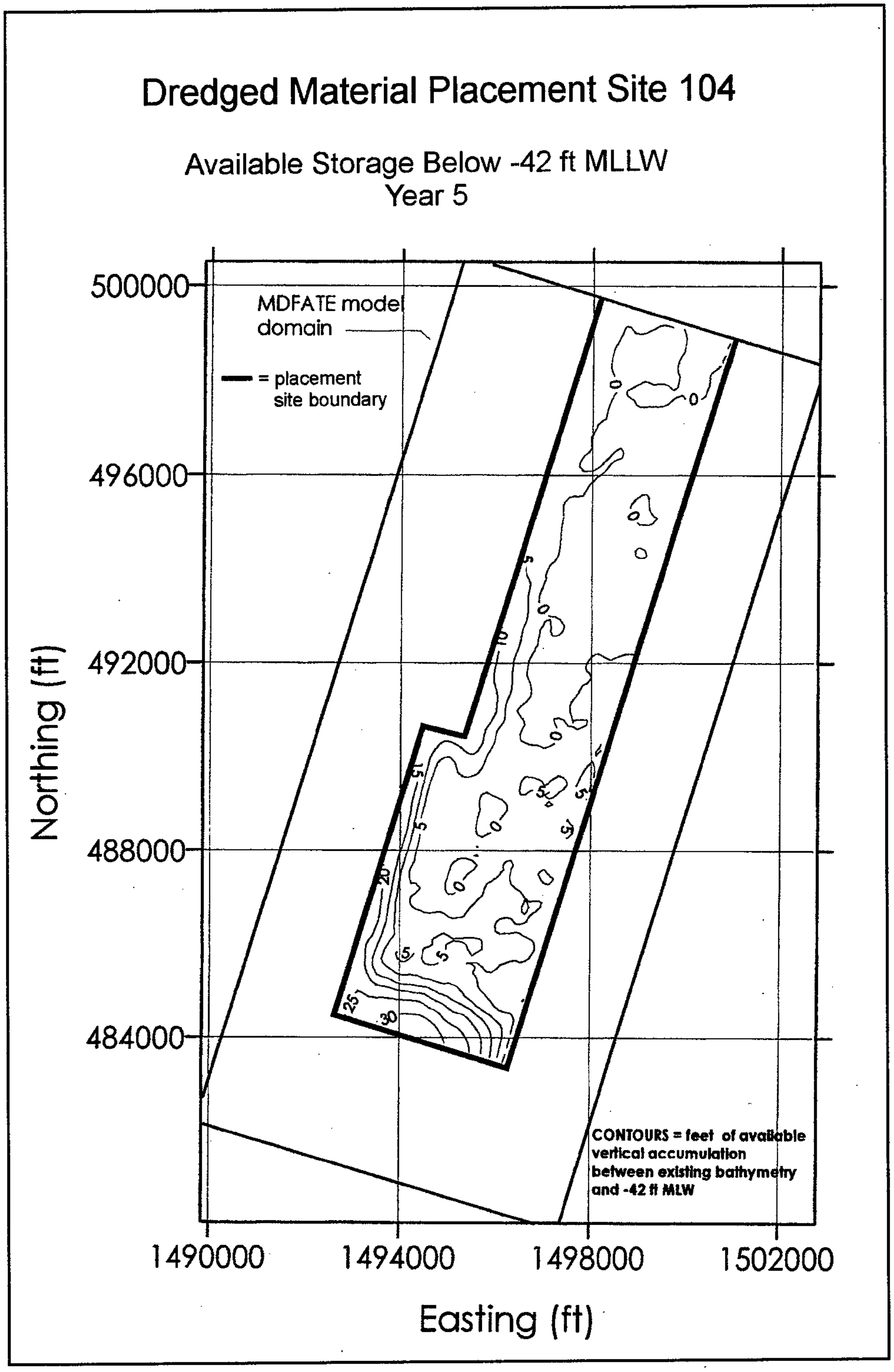

Figure 44. Capacity of Site 104 below -42 ft MLLW after Year 4

The x, y location of each cell (within the target area) to be used for a given placement cycle was recorded. Individual placement locations (per cell) were selected at random, using a 200-ft radius about each cell centroid. All generated placement coordinates were stored in an ASCII file and used by MDFATE to simulate placement for the entire year of interest. The above steps are repeated for each year of placement. Assigned placement coordinate locations for each of the 5 years of MDFATE simulation are shown in Figures 7-11.

Methods for Placing Dredged Material Within Site 104

Placement method No. 1—Placement using a scow or split-hull barge

Assumed scow or barge dimensions and operating characteristics used in the MDFATE simulations are shown below:

Per load capacity = 3,600 cu yd
Vessel length = 300 ft
Vessel beam = 50 ft
Loaded draft = 18 ft
Empty draft = 7 ft
Time required to empty each scow = 60 sec
Vessel speed during placement = 1.7 ft/sec
Direction vessel is approaching placement site from = South ± 45 deg

As described above, the method used to simulate the barge placement of dredged material within Site 104 was based on a random distribution of a specified number of placements about a group of predetermined placement-cell centroid coordinates.

Placement method No. 2—Hydraulic placement

This method involves pumping dredged material from a barge through a pipe located close (within 6 pipe diameters) to the site bottom. The hydraulic placement of dredged material within Site 104 was simulated within the MDFATE model based on a unit discharge of dredged material. For each unit discharge of 3,600 cu yd (volume of dredged material before placement), a characteristic bottom accumulation (or "footprint") of discharged dredged material was calculated by Moffatt & Nichol Engineers and WES based on work by Thevenot, Prickett, and Kraus (1992). One should refer to Chapter 8, Generation of Hydraulic Placement Footprint, for details. The "footprint" for each unit discharge of hydraulically placed dredged material was based on a characteristic mound having uniform height = 0.256 ft and radius = 423 ft. The distribution method used to assign the location for each unit hydraulic discharge "footprint" was the same as that used for the barge placement method (i.e., the same placement coordinates were used for both methods).

Dredged Material and Site 104 Characteristics (Short-Term Fate Calculations)

Dredged material parameters utilized in MDFATE were developed from information (Series II sediment tests) reported in Chapter 5, Erosion Tests. The dredged material proposed for placement within Site 104 was determined to be composed of three sediment "constituents": clumps, silt, clay. Although some sand was present within the sediment-sample data reported by WES, the relative percentage of sand was small enough (<5 percent) to have negligible influence on overall sediment behavior. Therefore, the sand fraction was assumed to be part of the "clump" component. Characteristics for each sediment constituent are described below in Table 14 and are based on Series II sediment-testing results (one should refer to Chapter 5, Erosion Tests).

Table 14
Sediment Physical Characteristics for Short-Term Fate Computations (Series II Results)

Material	S. G.	Solids Conc.	Grain Diam, mm	Dep Voids Ratio	Cohesive
Clumps	1.6	0.0100	300	0.4	N
Silt	2.65	0.0910	0.07	8.850	N
Clay	2.65	0.0590	0.003	8.850	Y

The density profile of water at Site 104 was taken to be 1.010 g/ml at the surface and 1.020 g/ml at the bottom.

Based on the above sediment parameters, the full "potential" volume per placement expected to be deposited on the bottom of the estuary was 5,363 cu yd. One should note that each load of dredged material, as contained in the barge was estimated to be 3,600 cu yd. The effective "bulking" factor for placed dredged material immediately after placement is 1.49 (5363/3600). The long-term process of consolidation will act to reduce the volume (but not the mass) of placed dredged material to its original volume, as removed from in situ.

Placed Dredged Material and Site 104 Characteristics (Long-Term Fate Calculations)

The preplacement bathymetry within the Site 104 MDFATE domain was considered "fixed" with respect to these simulations. In addition, each preceding year of the 5-year simulation was also considered fixed with respect to the next active year of MDFATE simulation. For example, during Year 3 of the MDFATE simulation, all dredged material that had been placed during Years 1-2

was considered "fixed" and not subject to erosion or consolidation beyond what was predicted in Years 1-2.

The areal and vertical configuration of aggregate dredged material mounds at an ODMDS is controlled by the shearing angle and postsheared angle of the dredged material. As dredged sediments are continually placed (load by load) within a specific open-water area, the material builds laterally and vertically. Geometrically, the extent to which the material accumulates is limited by the steepest angle at which the material can sustain itself before gravity (and environmental forces) forces the material to slump and redistribute downslope. The slumped sediment comes to rest when some equilibrium angle is reached. The limiting angle of repose (shearing angle) for subaqueous dredged sediments is the steepest angle the material can attain before slumping. The postsheared angle defines the slope of the slumped dredged material after it has come to rest (Larson and Kraus 1989; Allen 1970). The range in slump angles varies considerably with material type and the forcing environment. Reported values for the subaqueous angle of repose (shearing angle) for sand placed on the seabed range from 1.8 to 8 deg (USACE 1995).[1] Reported values for the angle of repose for highly disturbed and minimally disturbed cohesive sediments placed on the seabed are 0.3 and 10 deg, respectively.

At Site 104, the angle at which placed dredged material begins to slump (shearing angle) was assumed to vary between 1.7 to 2.0 deg. These values are based upon assessments of similar types of dredged material placed at the New York Dump Site (Clausner et al. 1998). The angle at which slumping stops (postsheared angle) once it has begun was estimated to be 1.6-1.9 deg. These values defined the steepness at which dredged material was permitted to accumulate during the Site 104 MDFATE simulation. Values for limiting dredged material slopes are summarized as follows:

a. Maximum shearing angle (steepest angle of new accumulation) = 2.0 deg for barge placement and 1.7 deg for hydraulic placement.

b. Postsheared angle (new material angle after shearing) = 1.9 deg for barge placement and 1.6 deg for hydraulic placement.

c. Maximum existing bathymetry angle observed at Site 104 = 5.6 deg.

In addition to accounting for dredged material slope redistribution (slumping), MDFATE simulates two processes to calculate the long-term fate of placed dredged material: Long-Term Sediment Erosion and Consolidation. The process of sediment erosion acts to remove sediment (volume and mass are reduced) from the bottom accumulation of dredged material. The process of consolidation acts to compress the accumulated volume of dredged material (volume is reduced, but mass is conserved).

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[1] Personal Communication, 1995, B. H. Johnson, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS (Regarding construction of subaqueous sill for preventing salt wedge intrusion on lower Mississippi River).

MDFATE Sediment-Erosion Calculations at Site 104

Sediment erosion (at the seabed), as calculated in MDFATE, is a function of the bottom shear stress because of waves/currents and assigned dredged material erodibility parameters. MDFATE uses the modified Ariathurai-Partheniades erosion model as defined in Chapter 2, Discussion of Models, MDFATE, of this report (Equation 1).

The erodibility parameters used in this simulation were varied based on the age of "deposited" dredged material. Placed dredged material that was 1 week or "younger" was assumed to be more erodible and compressive than material older than 1 week. Therefore, two sets of "erosion rate" parameters were used: one for "young" material (less than 1 week old) and another set for "old" material (older than 1 week). If the placed dredged material was older than 1 year, then the sediment was considered to be part of the Site 104 morphology and modeled as being "fixed." The parameters τ_c and M (see Equation 1 in Chapter 2, Discussion of Models - MDFATE) were determined from the Series II laboratory tests (Chapter 5, Erosion Tests), using sediment (core) samples obtained from various navigation channels in upper Chesapeake Bay. Erodibility parameters used in the MDFATE simulation at Site 104 are summarized below:

a. τ_c (new) = critical erosion shear stress for placed dredged material younger than 1 week = 0.00456 lb/sq ft.

b. M(new) = transport-rate mobility number (coefficient) for placed dredged material younger than 1 week = 0.1466 lb/sq ft/hr.

c. τ_c(old) = critical erosion shear stress for placed dredged material older than 1 week = 0.0146 lb/sq ft.

d. M(old) = transport-rate mobility number (coefficient) for placed dredged material older than 1 week = 0.615 lb/sq ft/hr.

As previously discussed, for the Site 104 application, the bottom shear stress (τ_b) for each grid point in the MDFATE domain was predetermined based on results obtained from the numerical model CH3D-WES. As long as the critical shear stress for erosion (τ_c) is exceeded, placed (younger than 1 year) dredged material will be eroded according to the erosion model specified by Equation 1.

MDFATE Consolidation Calculations for Site 104

Self-weight consolidation of placed dredged material was simulated in MDFATE using a finite strain concept (Cargill 1985; Poindexter-Rollings 1990). In the finite strain formulation used for estimating consolidation in MDFATE, the time rate of dredged material consolidation is a function of voids ratio,

effective stress, and permeability. For the Site 104 analysis, the data characterizing the time history of dredged material consolidation were based on data developed by Clausner et al. (1998) for the New York Mud Dump Site.

The three time-history consolidation parameters described above were supplied (based on WES-CHL laboratory tests) in a format compatible with the file structure used in the consolidation programs. The time history (covers 1 year) of the parameters provided for a continuous calculation of consolidation for young and old materials. The consolidation file (PCDDF) parameters are shown below for completeness. The more interested reader should refer to Cargill (1985) and Poindexter-Rollings (1990) for details. Each line starts with a line number. The entries on line number 10 are the specific gravity of the material, the number of entries to follow, the voids ratio at time = 0.0, the specific gravity of water, and the number of vertical layers. Entries on line numbers 20-230 are voids ratio, effective stress, and permeability. Entries on the last line (No. 240) are voids ratio, permeability, and drainage-path length of the foundation material.

Data file used to estimate consolidation

```
10  2.64  22  8.85  62.4  10
20  8.90  0.00E+00  4.80E-01
30  8.80  2.80E-02  4.45E-01
40  8.40  6.44E-02  3.25E-01
50  8.00  1.08E-01  2.37E-01
60  7.80  1.34E-01  2.03E-01
70  7.40  2.00E-01  1.50E-01
80  7.00  2.74E-01  1.08E-01
90  6.60  4.00E-01  7.75E-02
100 6.20  6.10E-01  5.56E-02
110 5.80  9.30E-01  4.00E-02
120 5.40  1.46E+00  2.82E-02
130 5.00  2.30E+00  2.00E-02
140 4.60  3.80E+00  1.38E-02
150 4.20  6.34E+00  9.50E-03
160 3.80  1.09E+01  6.40E-03
170 3.40  1.92E+01  4.25E-03
180 3.00  3.36E+01  2.80E-03
190 2.60  6.00E+01  1.75E-03
200 2.20  1.16E+02  1.08E-03
210 1.80  2.35E+02  5.70E-04
220 1.40  4.80E+02  2.58E-04
230 1.20  7.70E+02  1.13E-04
240 1.00  1.00E-06  100.0
```

The initial condition for dredged material within the MDFATE simulation was based on the following "starting time" voids ratios (e). They were calculated based on a 15-ft-thick mound using the above PCDDF data file and "starting times" as indicated below:

a. For new material just after deposition (time = 0), e = 8.40.

b. For old material that has been on bottom for 1 week (time = 7 days), e = 7.9.

c. For old material that has been on bottom for 1 month (time = 30 days), e = 6.6.

d. For old material that has been on bottom for 2 months (time = 60 days), e = 5.7.

e. For old material that has been on bottom for 4 months (time = 120 days), e = 4.8

Results from the Swan Point erosion tests indicated initial bulk voids ratios up to 15 for the slurried sediments. However, the bulk voids ratio for the more representative composite material (Series II) was about 11. The consolidation database in MDFATE only allows for a bulk voids ratio as high as 8.4, which required selecting this value for use in MDFATE for new material just after deposition. However, this does not significantly impact the influence of consolidation over a year. As deposited dredged material undergoes primary consolidation, the long-term rate of consolidation decreases asymptotically. Since most of the primary consolidation occurs within 6 months of initial deposition, the difference between using an initial voids ratio of 8.4 versus 11 is not expected to produce consolidation results that are very different at the end of a 1-year simulation.

Simulated Flow Conditions at Site 104

As previously discussed, the tidal elevation and current data used in MDFATE for the Site 104 analysis came from depth-averaged computations in the CH3D-WES model. In CH3D-WES, both depth-averaged flow fields and fully 3-D fields are computed. The two-dimensional water surface elevation field is computed in the depth-averaged computations and then "fed" into the 3-D computations as part of the horizontal pressure gradient term. Since MDFATE utilizes a depth-averaged flow field, the depth-averaged velocities from CH3D-WES were used. For each 3-hr time step in the five 1-year MDFATE simulations, the depth-averaged CH3D current data were "mapped" onto the entire MDFATE model domain using a multipoint interpolation scheme.

For STFATE calculations performed within MDFATE, the CH3D depth-averaged current field was modified to account for the vertical structure of the current observed at Site 104 (Chapter 6). The magnitude of the bottom current

during flood (south to north) flow has been observed to be approximately equal to the depth-averaged flood current magnitude (Figure 20). However, during ebb (north to south) flow within Site 104, the magnitude of the bottom current has been observed to be about 50 percent of the depth-averaged ebb current magnitude (Figure 21). To account for the observed reduction of ebb current near the bottom, the depth-averaged current used in STFATE (during the "bottom collapse phase" of calculations) was reduced by 50 percent when the current was exhibiting an ebb flow direction. During flood flow, no reduction was applied to the depth-averaged current. The reduction of ebbing currents was performed only for the "bottom collapse phase" of STFATE calculations. All other phases of calculations were performed using the full (unreduced) depth-averaged current. The impact of this flow reduction during ebb was to reduce the size of the bottom collapse cloud, resulting in slightly more of the material being deposited on the bottom.

As previously noted, the bottom shear stress data used in MDFATE were also obtained from the CH3D-WES model. For each 3-hr time step in the MDFATE simulation, the CH3D-WES shear stress data were "mapped" onto the entire MDFATE model domain using a multipoint interpolation scheme. It was assumed that the site bathymetry generated by barge placement would be close enough to that generated by hydraulic placement so that the same CH3D-WES solution each year could be used for both placement simulations.

Predicted Fate of Dredged Material Placed at Site 104

MDFATE computes two types of potential material loss: (a) loss during placement and (b) long-term loss after placement. Model results are presented for both types of losses for each year of MDFATE simulation.

During placement of dredged material, some material remains in the water column after the bottom-collapse phase and may be transported out of the site without ever being deposited on the site bottom. This is referred to as a "collapse loss." The "collapse loss" only occurs for the barge placement operation and only for the clay fraction. This is because some cohesive (clay) material is diffused to a low concentration during the bottom collapse process. Cohesive material with low-solids concentration settles out from the water column very slowly, on the order of several feet per day. By the time the last cohesive material has settled out of the water column, the material has already been transported beyond the MDFATE domain. A basic assumption for the hydraulic pump out method of placement is that all placed material is initially deposited on the estuary bottom since the end of the pipe will be placed close to the bottom. In reality, some of the material may not be immediately deposited given the magnitude of bottom currents and the fact that the material will be hydraulically slurried and discharged a few feet from the bottom. However, the assumption is consistent with observations at the Tylers Beach placement site (Thevenot, Prickett, and Kraus 1992).

Results for "collapse loss" for each year are given in Table 15. Taking into account the variability of volumes of material for different years (obtaining a weighted average), it can be seen that these "collapse losses" account for 3.3 percent of the total amount of solids placed at the site over the 5-year life of the placement project. Figures 45-49 (from which Table 15 was generated) show the variability of "collapse loss" for each year and for individual placements during each year. For Year 4, the "collapse loss" at the beginning of the operation is relatively high (Figure 48) because of placed material being carried out of the northern boundary of the MDFATE domain. However, since the actual Site 104 boundary extends 4,000 ft further north than the MDFATE domain, more material is expected to be deposited in the site than shown in Figure 48.

Table 15
Material Not Deposited for Barge Placement

Year	Percent of Material Not Deposited (collapse loss)
1	2.2
2	2.4
3	3.1
4	4.5
5	3.1
5-Year Weighted Average	3.3

After dredged material is deposited during placement, it may be eroded away if the bottom shear stresses are large enough. This is referred to as a "long-term loss." The potential "long-term loss" of dredged material placed at Site 104, for each year of MDFATE simulation, is presented as a time history of the predicted amount of eroded material by mass. Figures 40 and 50-53 show the cumulative time history of deposited mass being eroded for each year of placement for both placement methods. Again, remember that the bathymetry at the beginning of each year was assumed to be fixed. Figure 54 shows the predicted sediment loss for the existing bathymetry (before placement, thin line) and after 4 years placement (thick line), based on "old" material erodibility parameters. Figure 54 illustrates that assuming a fixed preplacement bathymetry is not entirely correct. The amount of "long-term loss" over the entire area of the Site 104 domain translates to less than 0.1 ft/year of erosion for the existing condition (Figure 55) and less than 0.3 ft/year after Year 4 of disposal (Figure 56).

One should note that this is contrary to the results reported by various researchers who have concluded that sedimentation rates in the deeper portions of Chesapeake Bay are generally higher than in surrounding waters. The deeper channels are relict features incised by the Susquehanna River and its tributaries during times of lower sea level, and they are now filling relatively rapidly with sediments (Colman, Halka, and Hobbs 1992). In the vicinity of Site 104, the long-term average rate of sedimentation accumulation (over 10,000 years) has been 3 mm/year (Colman and Halka 1990). Pollen-dating techniques applied to

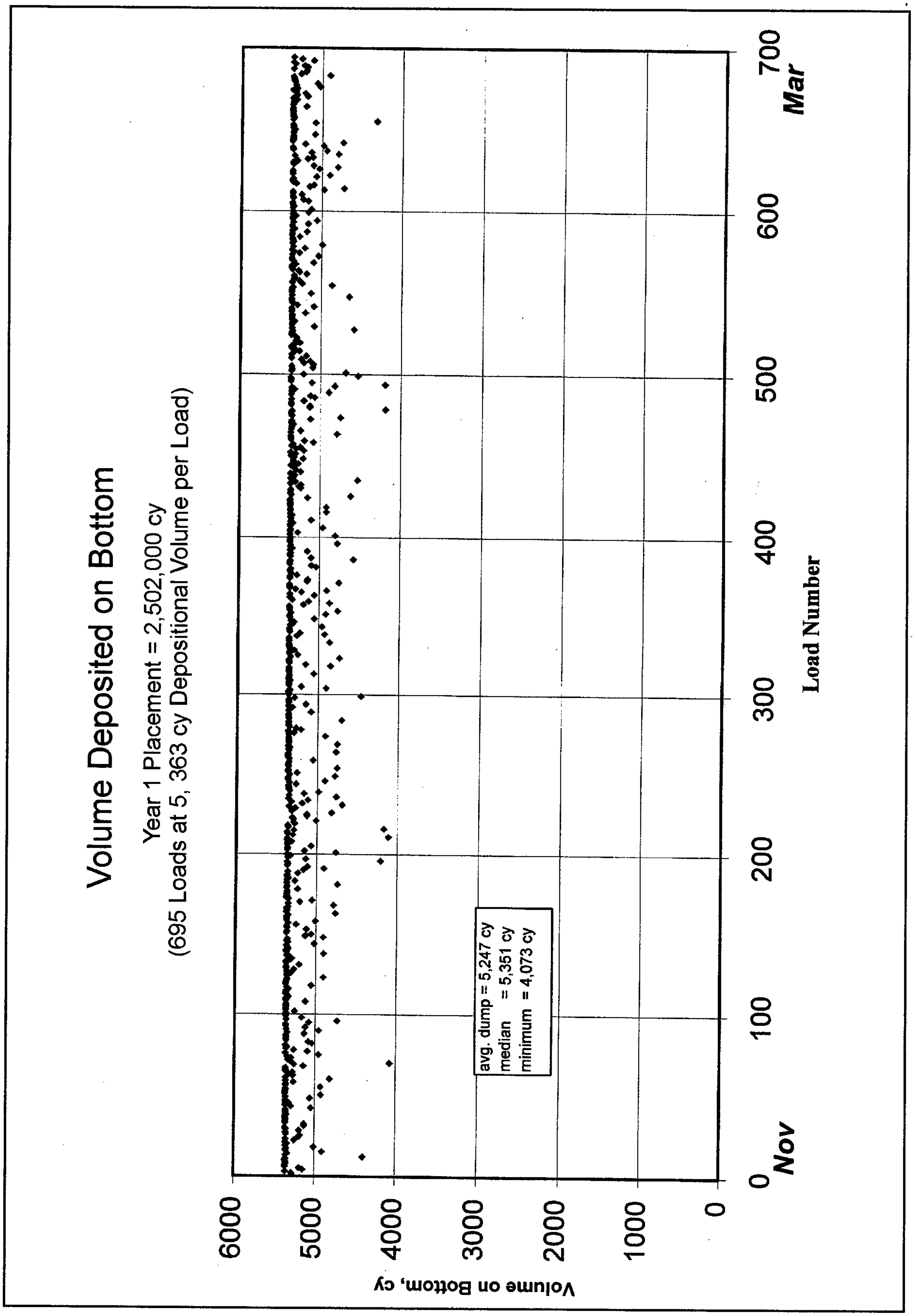


Figure 45. Volume of material initially deposited for Year 1

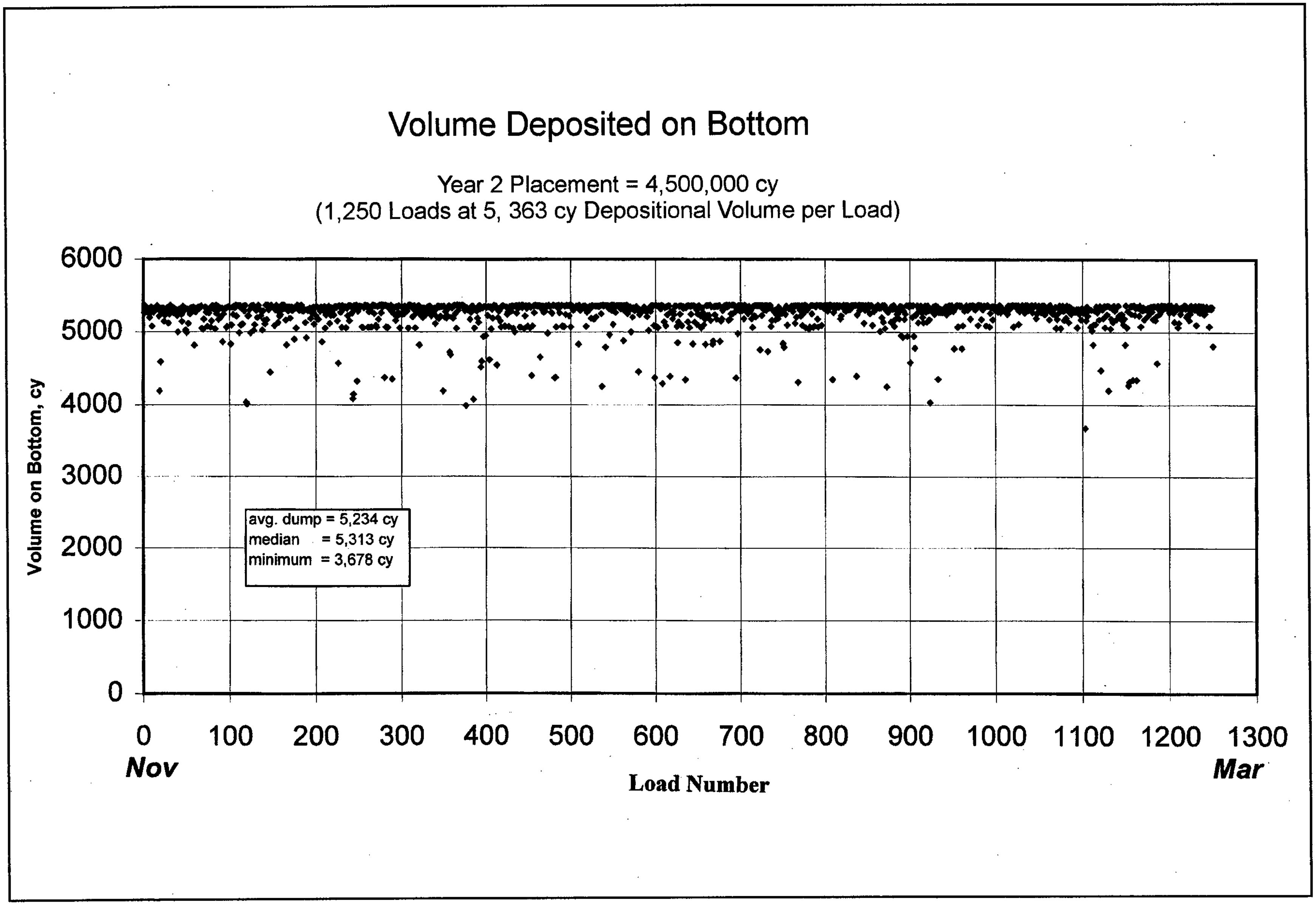


Figure 46. Volume of material initially deposited for Year 2

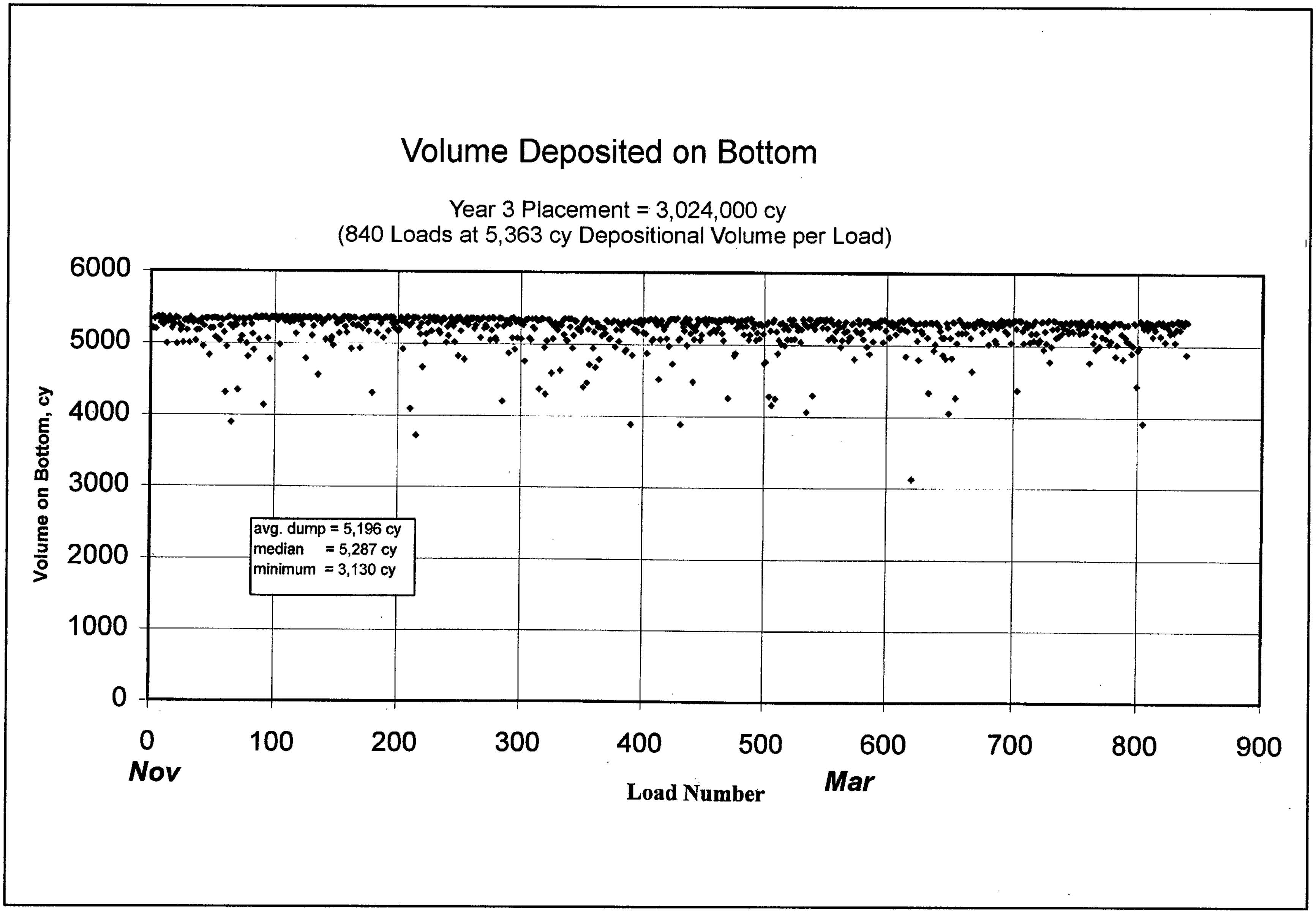


Figure 47. Volume of material initially deposited for Year 3

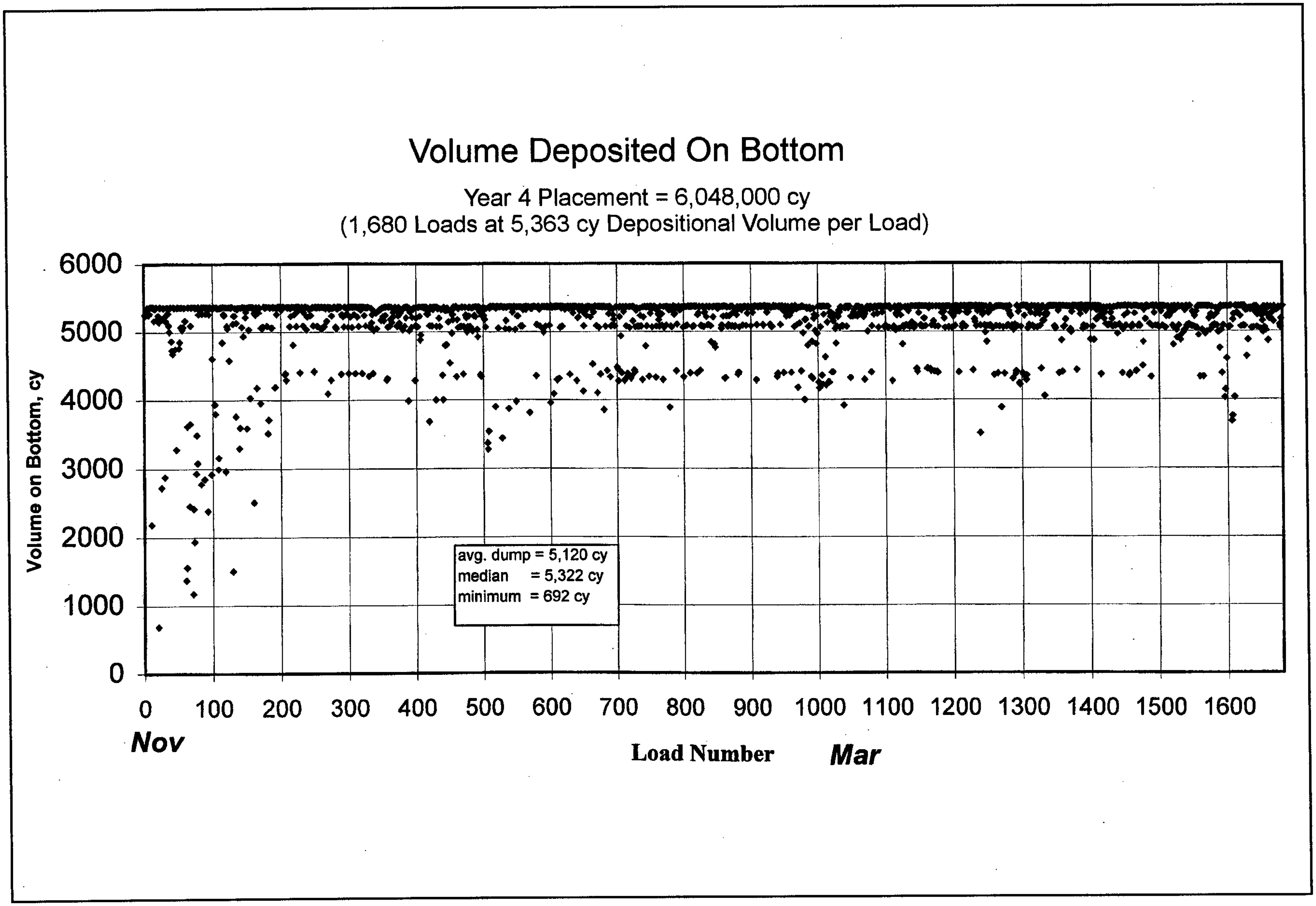


Figure 48. Volume of material initially deposited for Year 4

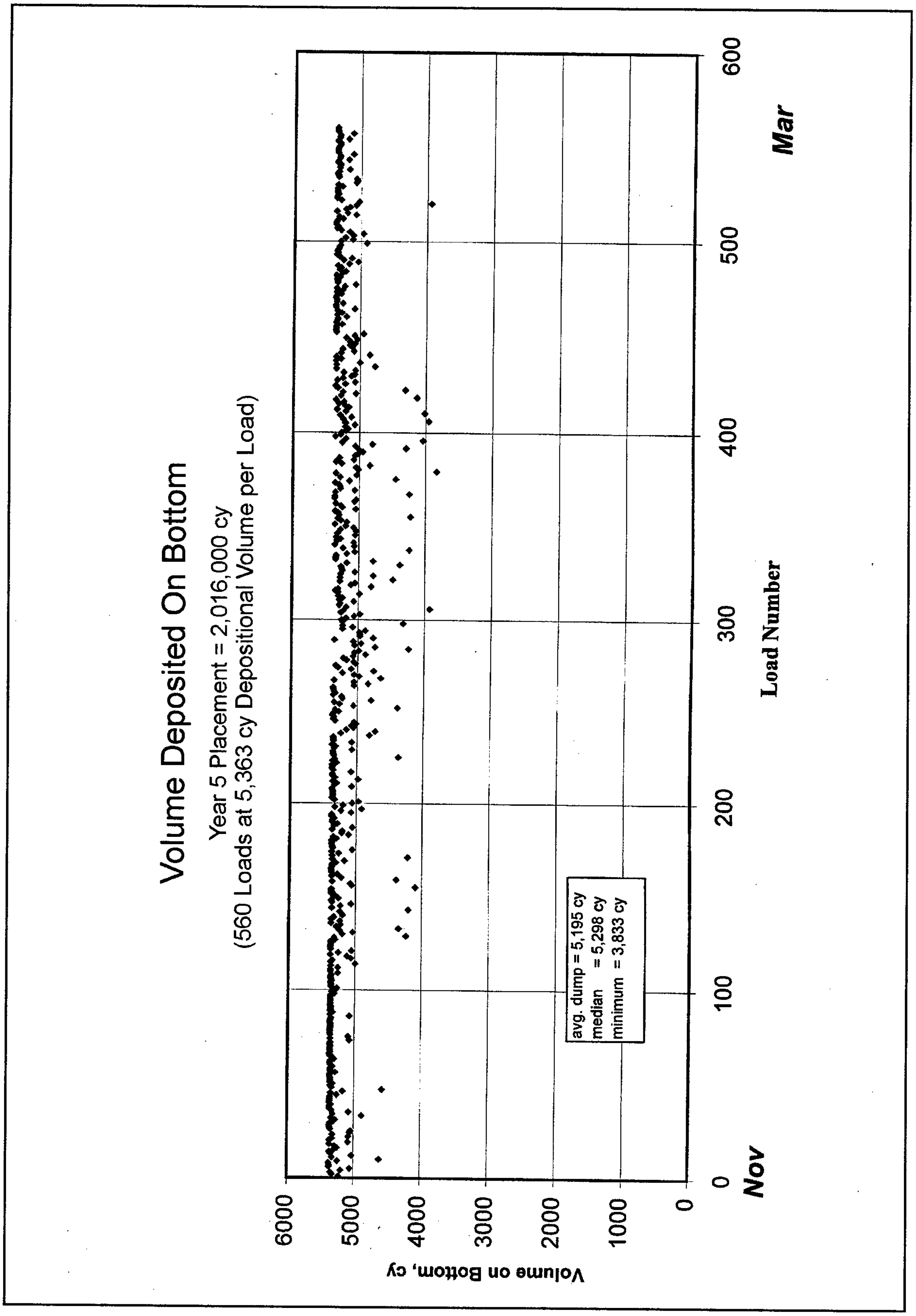


Figure 49. Volume of material initially deposited for Year 5

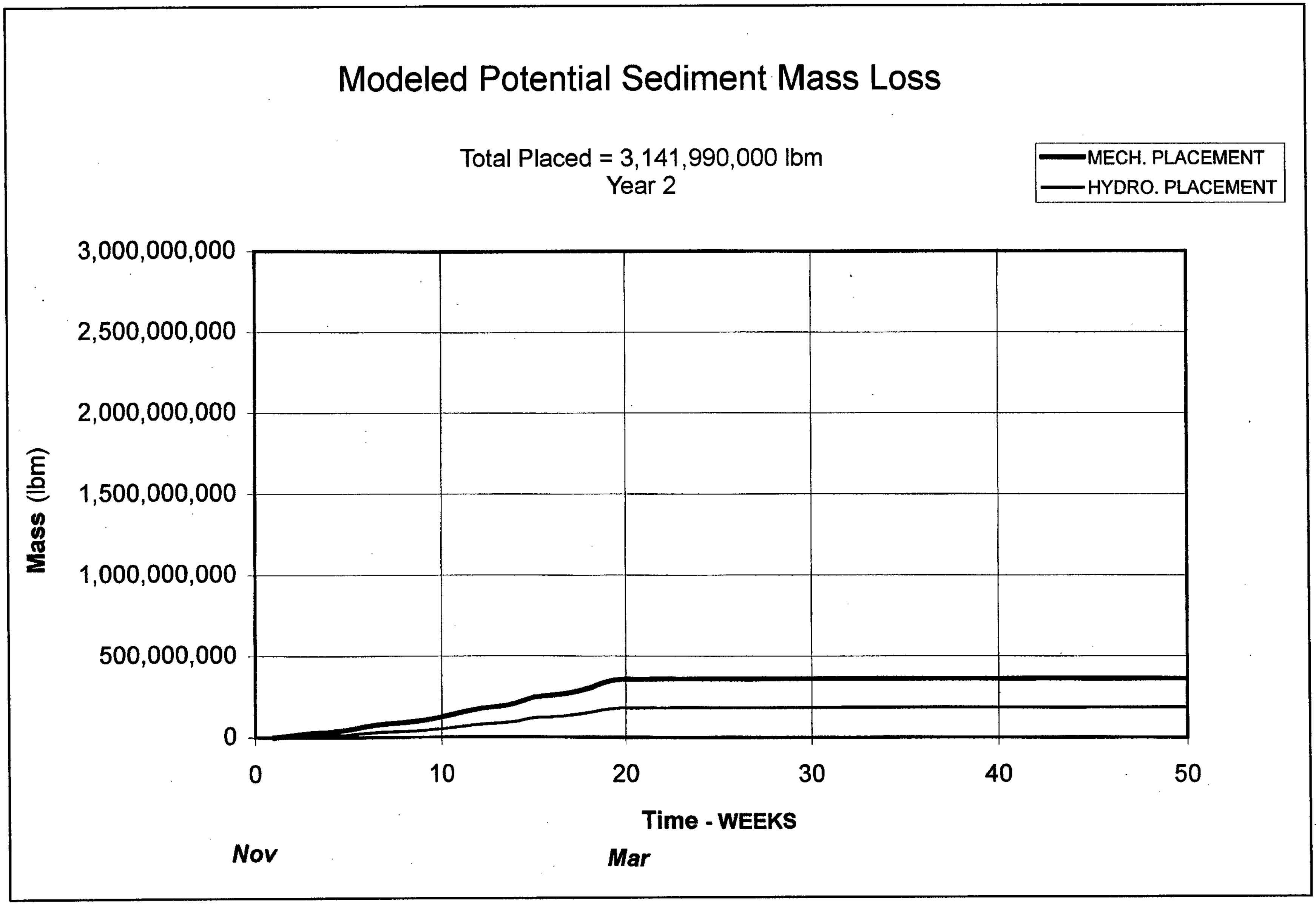


Figure 50. Cumulative deposited mass eroded for Year 2

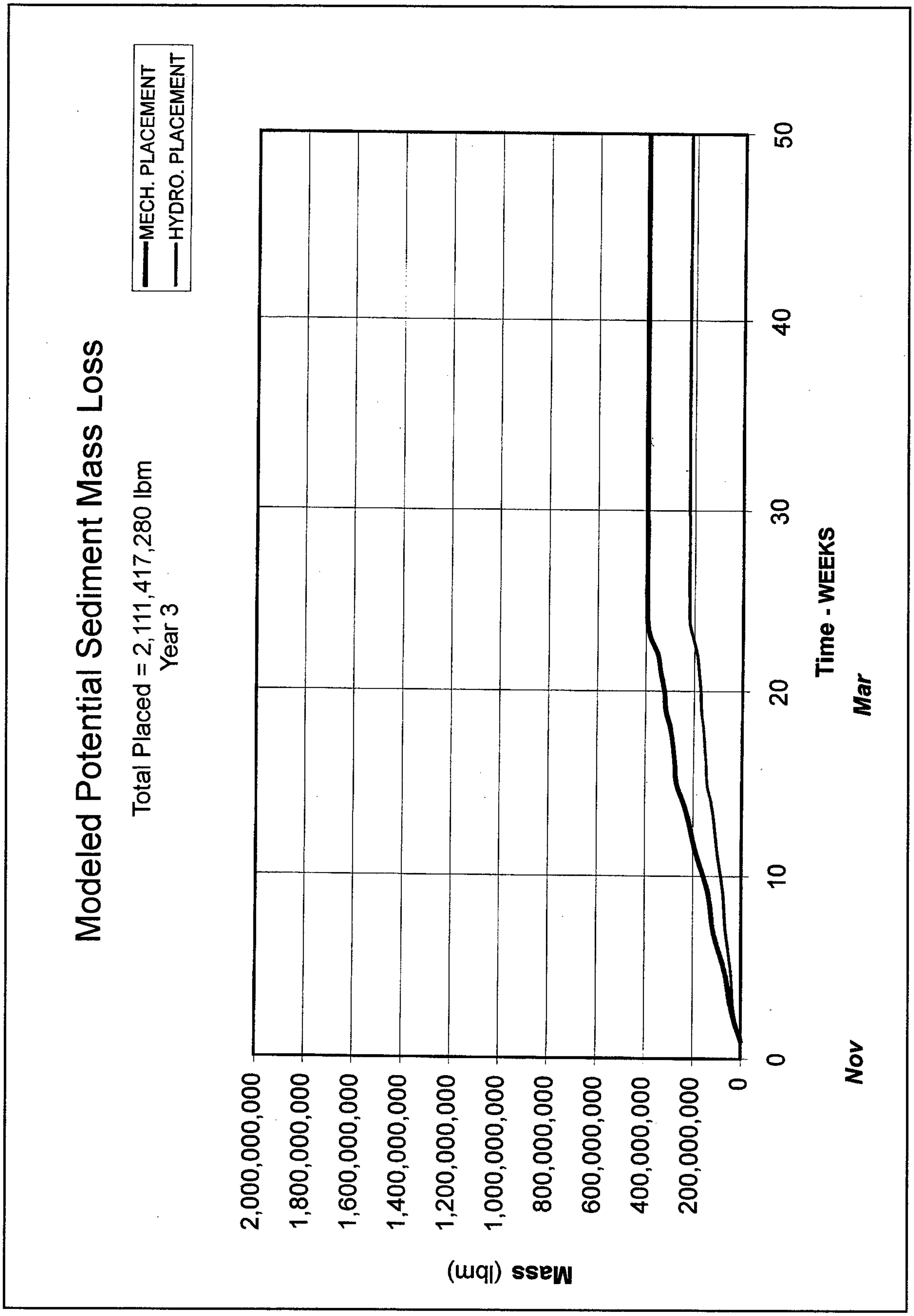


Figure 51. Cumulative deposited mass eroded for Year 3

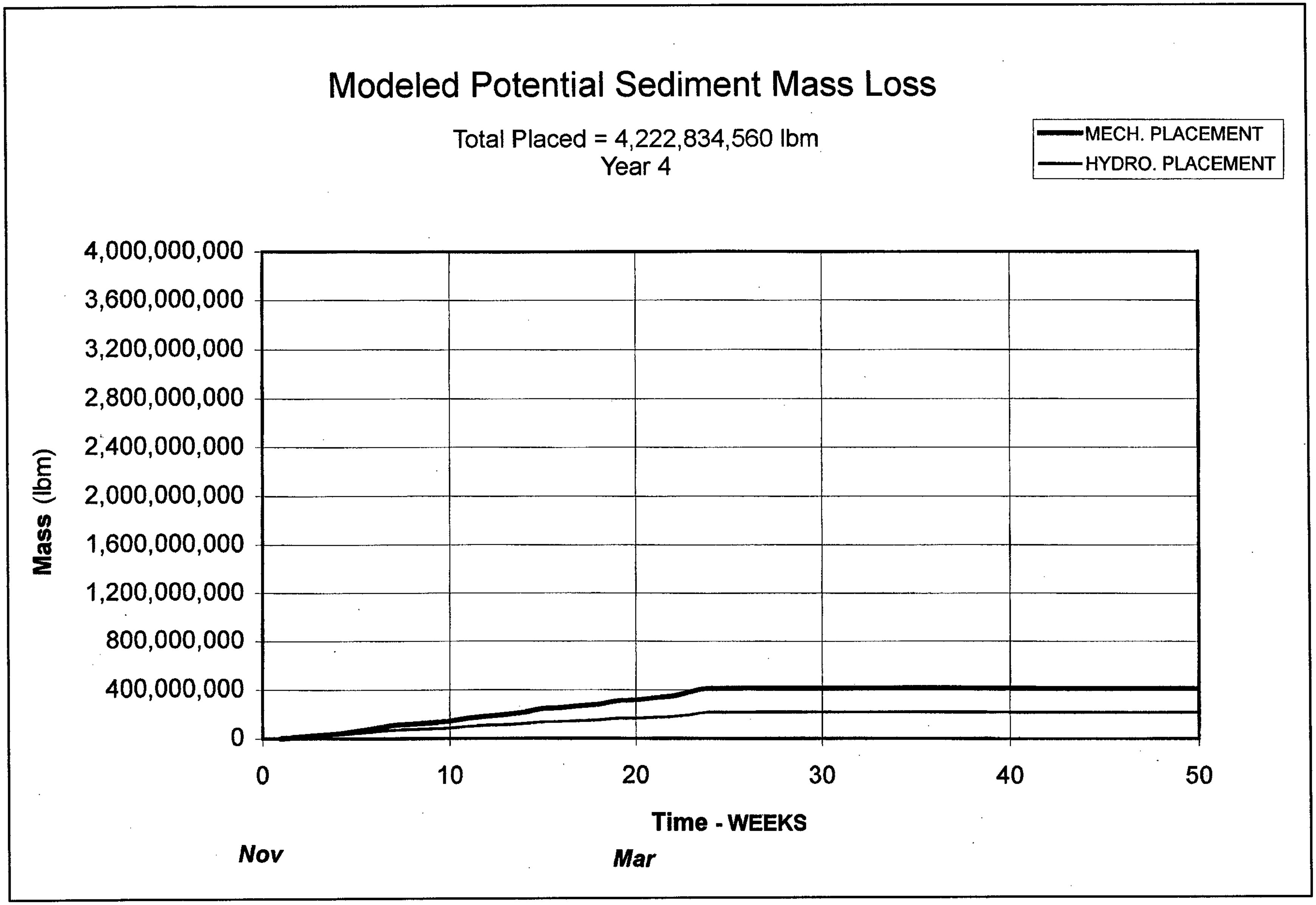


Figure 52. Cumulative deposited mass eroded for Year 4

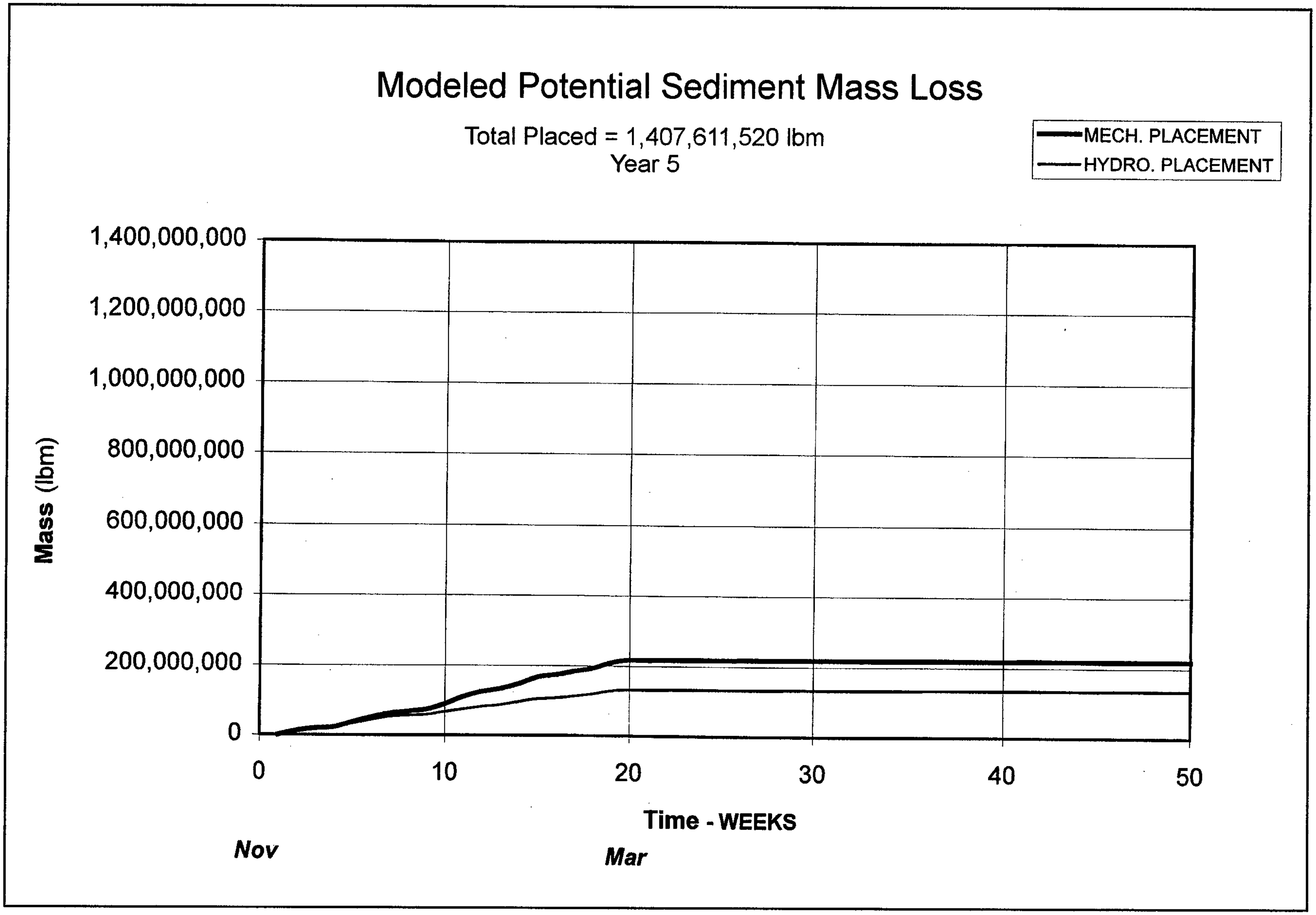


Figure 53. Cumulative deposited mass eroded for Year 5

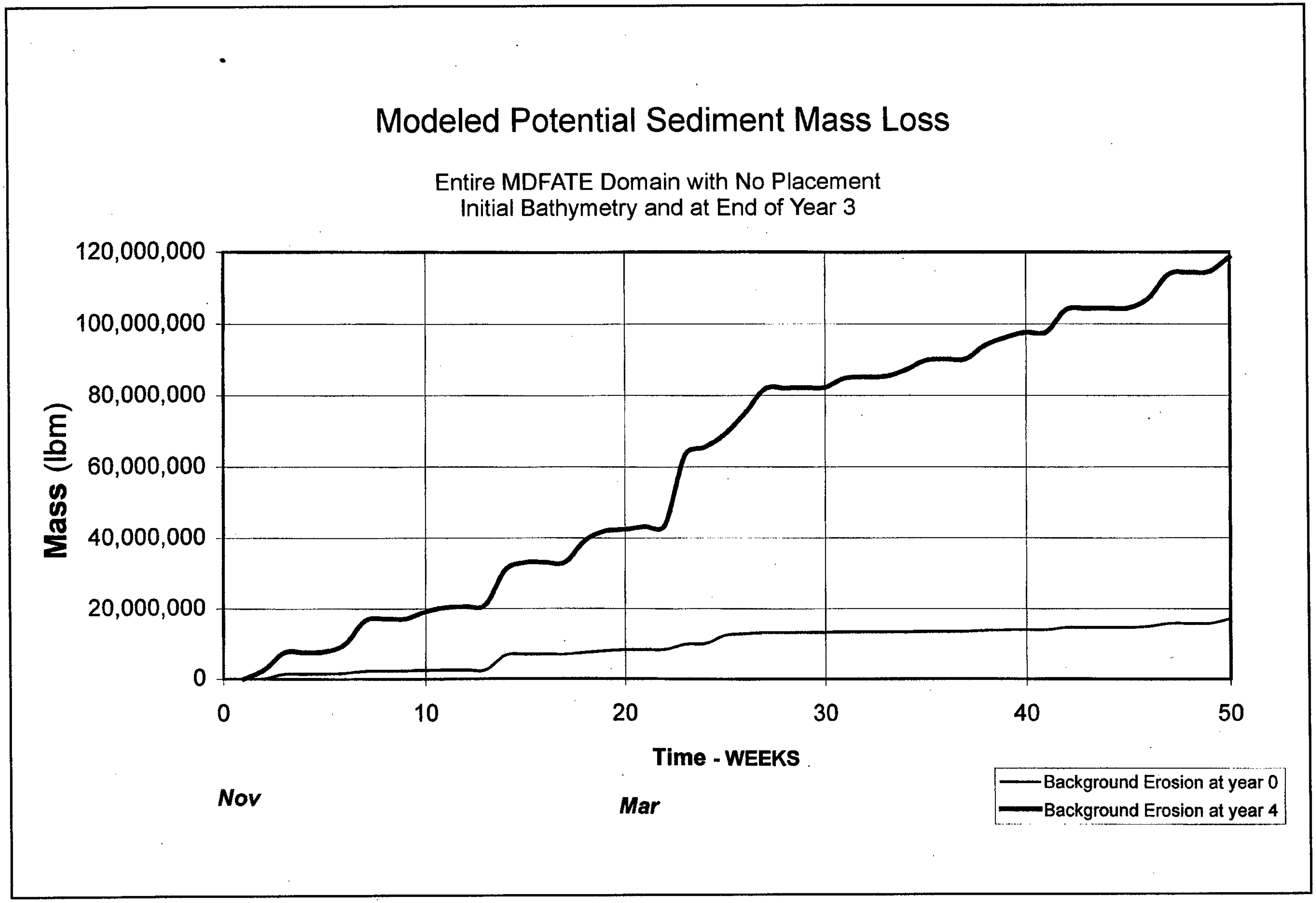


Figure 54. Cumulative mass eroded with no placement over 1 year using initial bathymetry and bathymetry after 3 years of placement

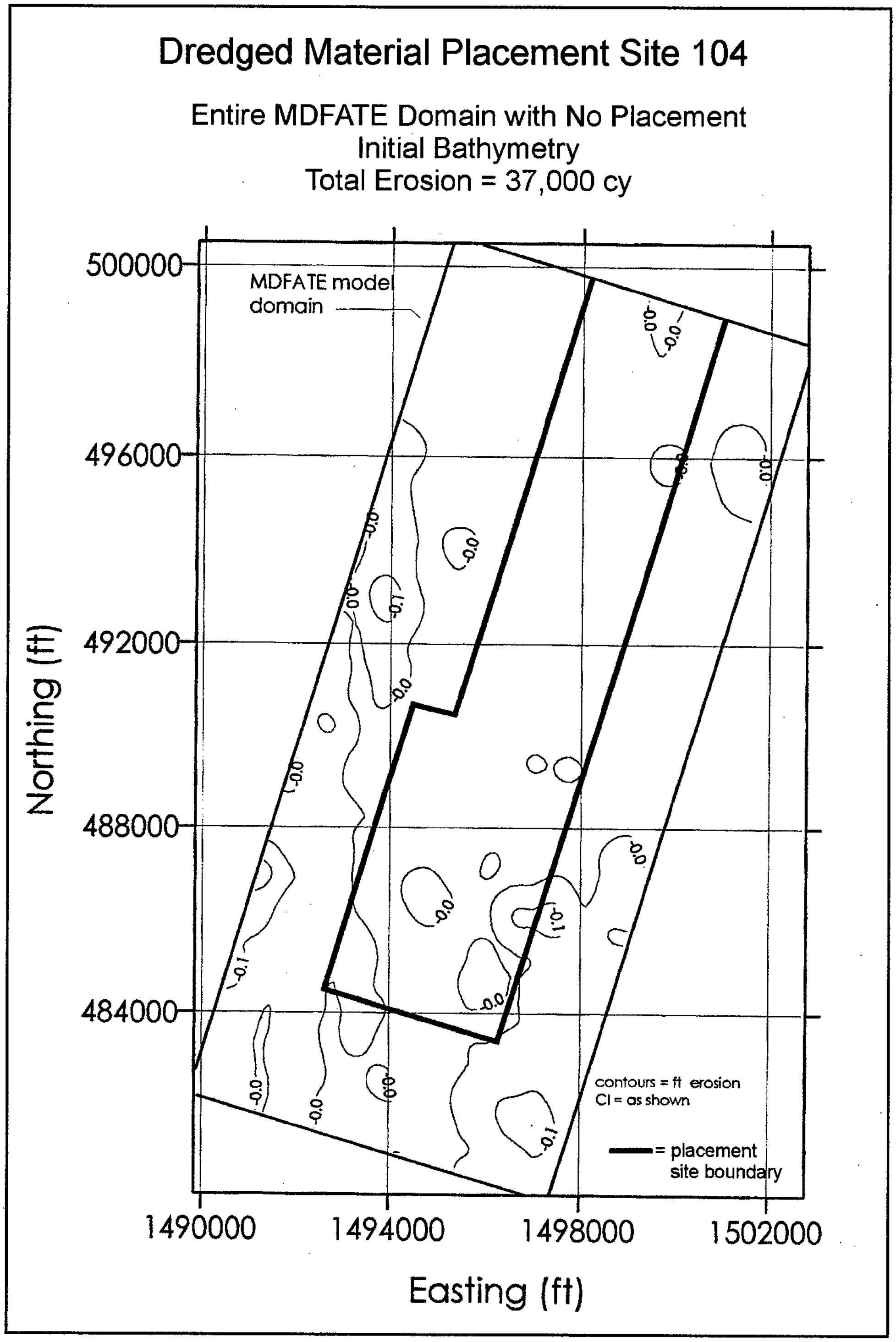


Figure 55. Change in initial bathymetry over 1 year with no placement of dredged material

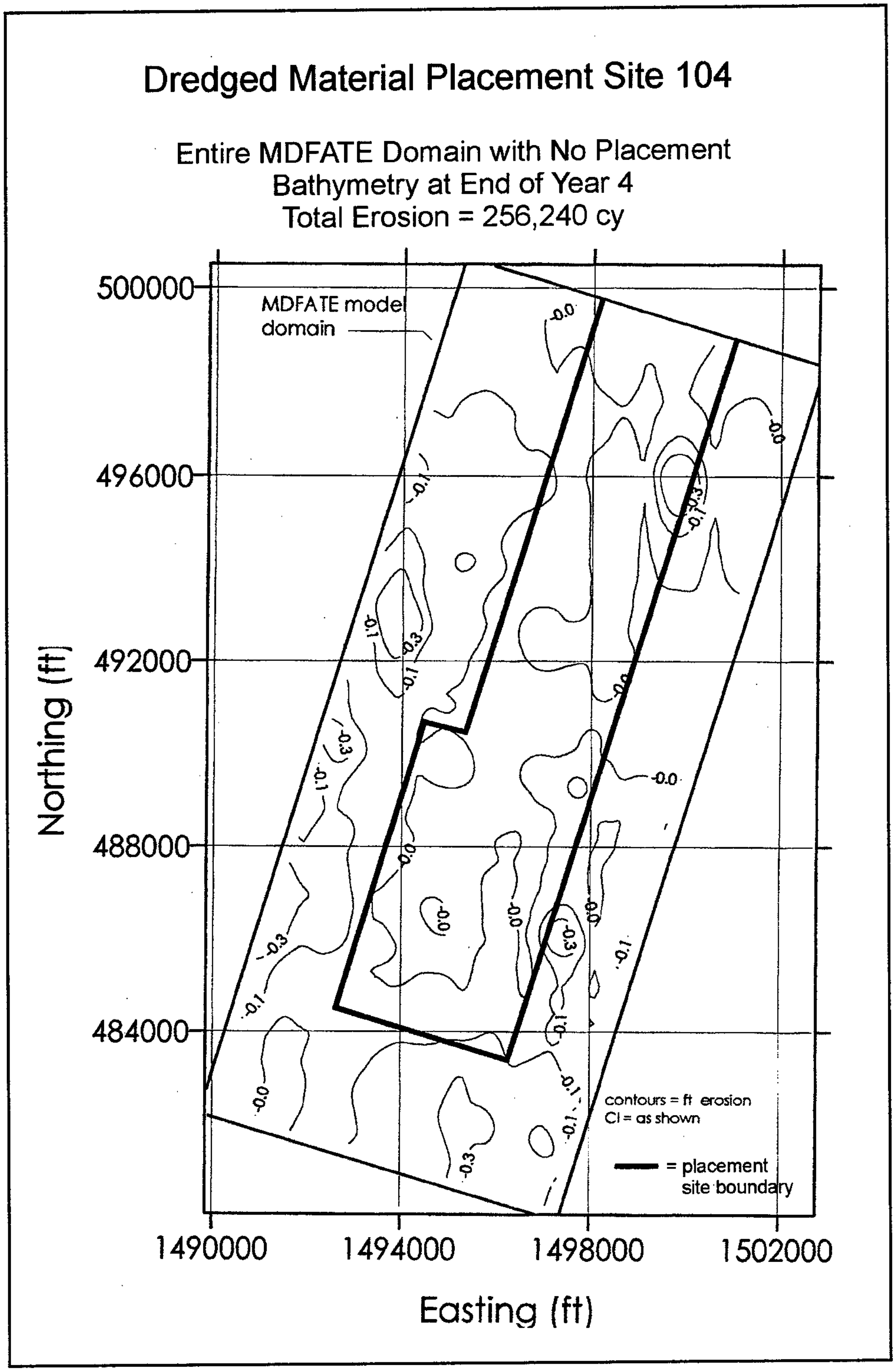


Figure 56. Change in site bathymetry over 1 year with no placement and using bathymetry after 4 years of placement

three recent sediment cores collected in the vicinity of Site 104 indicate that the rate of sediment accumulation since the time of European occupation has averaged approximately 4 mm/year (Brush 1990; Brush, Hill, and Unger 1997). Although these cores were not located within the site itself, and extrapolation of sedimentation rates from specific core locations is questionable, the results corroborate the long-term average. Higher sedimentation rates (10 to 30 mm/year) have been calculated from radio nuclide dating of two cores collected from the bottom of the deep-water area off Kent Island (Golberg et al. 1978).

One can see from Figures 40 and 50-53 that most of the erosion takes place immediately after deposition of the material. One should recall that the erosion model is different for material more than 1 week old where material "younger" than 1 week is more erodible than material "older" than 1 week. For the barge method of placement, the total amount of placed material that is eroded away each year ("long-term loss") ranges from a low of about 9.5 percent for Years 2 and 4 to a high of 18.9 percent for Year 3 (Table 16). The "long-term loss" for the hydraulic method of placement ranges between 4.0 and 10.4 percent. The reason for the difference in "long-term loss" between years is due to the selected placement plan each year. When the individual placements are spread over a large area, the erosion increases (because of increased surface area of the overall accumulation footprint). As previously noted, the effect of placement spreading is shown in Figure 40. Again, one should note the increased mass loss because of the "uniform spreading method" (Figure 6) versus the "modified placement plan" method (Figure 7) for Year 1. This is discussed in the above section titled Strategy for Utilizing the Site 104 Capacity.

Table 16
Total Percent of Dredged Sediment Placed at Site 104 Estimated to be Eroded (long-term loss)

	Total Percent Eroded (long-term loss)	
Year	Bottom Dumping	Hydraulic Placement
1	16	6.3
2	9.5	4
3	18.9	10.4
4	9.5	4.7
5	15.6	9.2
5-Year Weighted Average	12.6	6.2

For barge placement, the total potential sediment loss is the sum of sediment stripped during descent through the water column (less than 1 percent in Table 9), material that never deposits (average collapse loss = 3.3 percent, Table 15), and material that is eroded after initial deposition (average long-term loss = 12.6 percent, Table 16). These results indicate that about 17 percent of the total solids (mass of dredged material) placed at Site 104 over the 5 years are potentially lost with the barge placement method and about 6 percent are potentially lost with the hydraulic placement method. One should recall that the

hydraulic placement method was assumed to not be subjected to material losses during placement (about 4.3 percent for the barge method).

Predicted Bathymetric Change at Site 104 Because of Dredged Material Placement

Figures 57-61 show the site bathymetry at the end of each year of barge placement. The difference between the initial bathymetry (Figure 4) and the cumulative bathymetry at the end of each year is given in Figures 62-65. The results of year-to-year differences for Site 104 bathymetry are shown in Figures 66-69. Year-to-year differences show only the accumulation of each placement year rather than the cumulative effect. One should remember that the computed bathymetry reflects the processes of slumping and consolidation as well as erosion of placed dredged material mass.

Comparing the total possible depositional volume of dredged material and water (approximately 27,000,000 cu yd) placed at Site 104 over 5 years with the volume remaining (approximately 17,000,000 cu yd) (see Figure 61) indicates a 37-percent decrease in volume for the barge method of placement. One should recall that the depositional volume of dredged material solids is the total volume of placed dredged material (18 million cu yd) times the solids concentration times (1 + bulk-voids ratio). A similar computation for the hydraulic placement method at the end of 5 years (Figure 74) indicates a volume decrease of 27.4 percent. These percentages are based on volume loss and differ from those based on mass loss shown in Table 16; i.e., 12.6 percent for the barge placement and 6.2 percent for the hydraulic placement. Figures 61 and 74 reflect volume loss because of consolidation as well as material loss because of erosion of the deposited solids. Thus, the percentages of mass loss are more meaningful when assessing the potential for placement material being removed from Site 104.

The MDFATE computations merely indicate that a certain percent of the placed material will be eroded from the bed. Possibly, some of this material will be redeposited on the Site 104 bed before being transported from the site. In results obtained from the water quality model where a "tracer" was injected into the bottom layer overlying Site 104, one simulation was made with the tracer possessing a settling rate of 0.5 m/day. That simulation implied that most of the "tracer" would settle out within Site 104. However, this does not truly reflect the behavior of suspended sediment transport since the deposition (as well as the erosion) of fine-grained sediment is dependent upon the magnitude of the bottom-shear stress.

For the hydraulic placement operation, bathymetry plots similar to those discussed above are shown in Figures 70-83. It can be seen that higher mounds occur with the hydraulic placement than for the barge placement operation. This is because the total footprint (surface area) resulting from multiple placements of the hydraulic footprint is smaller than the barge placement method, resulting in more vertical accumulation and less erosion taking place per annual placement cycle.

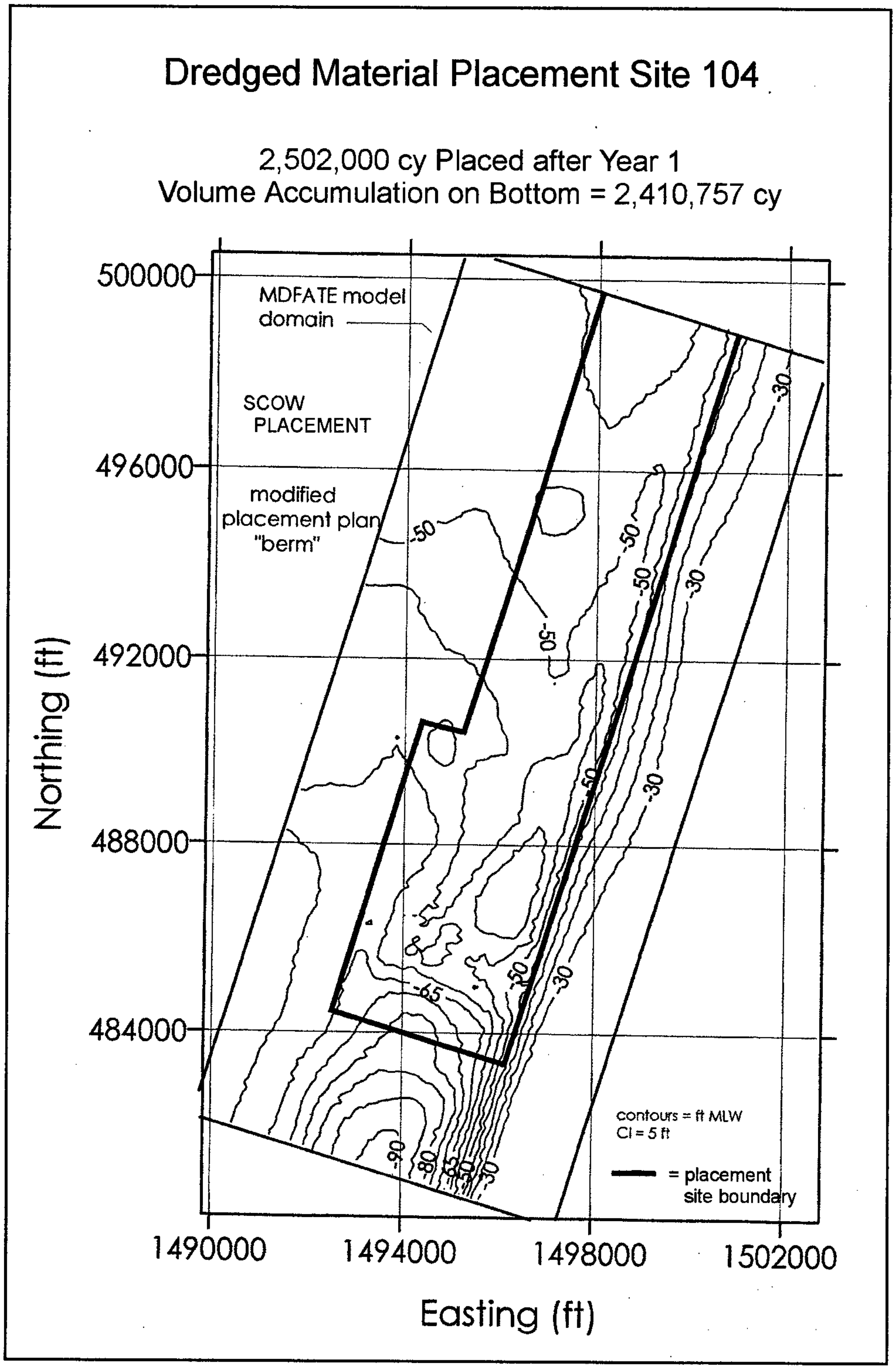


Figure 57. Site bathymetry after 1 year of barge placement

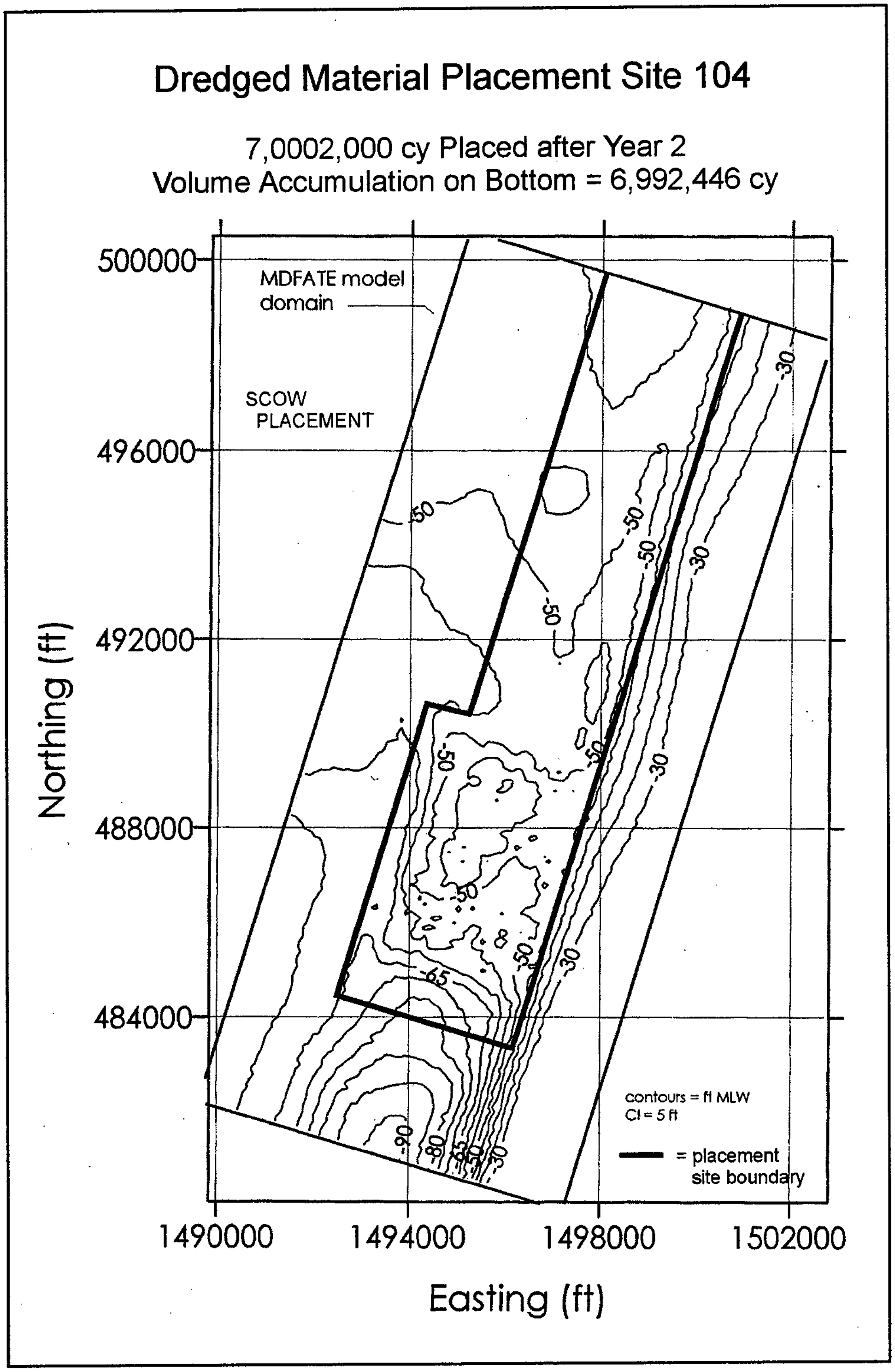


Figure 58. Site bathymetry after 2 years of barge placement

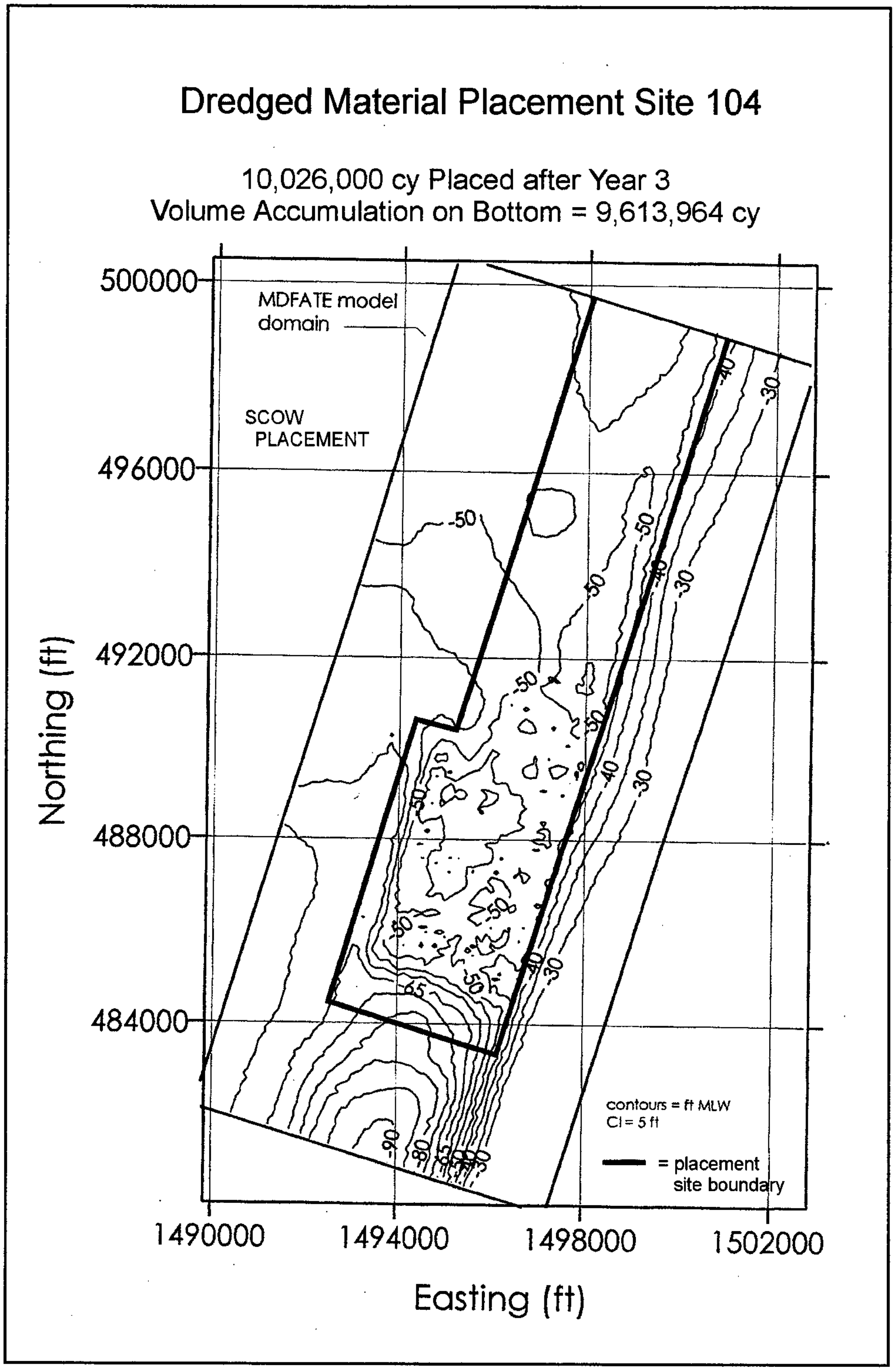


Figure 59. Site bathymetry after 3 years of barge placement

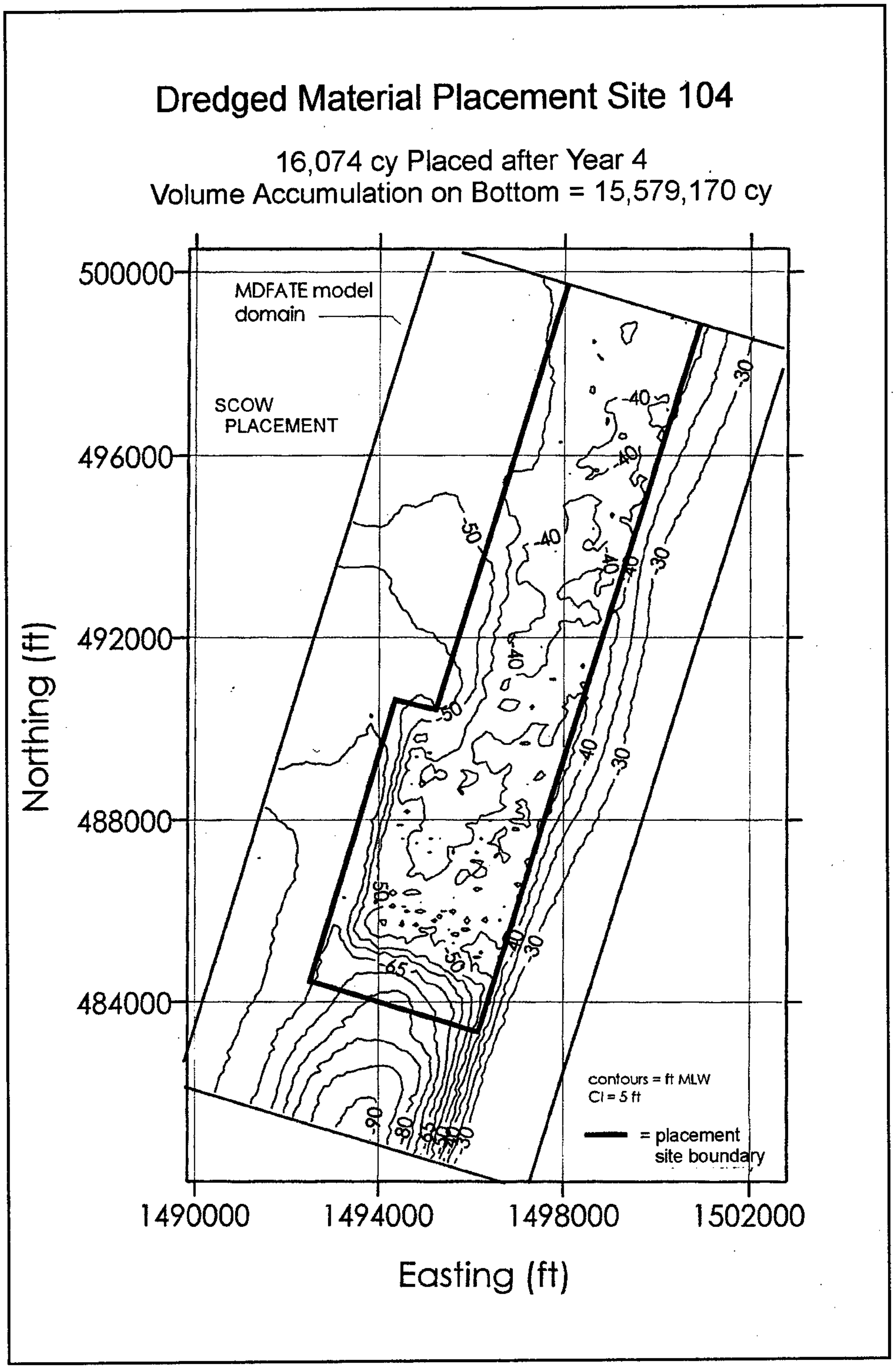


Figure 60. Site bathymetry after 4 years of barge placement

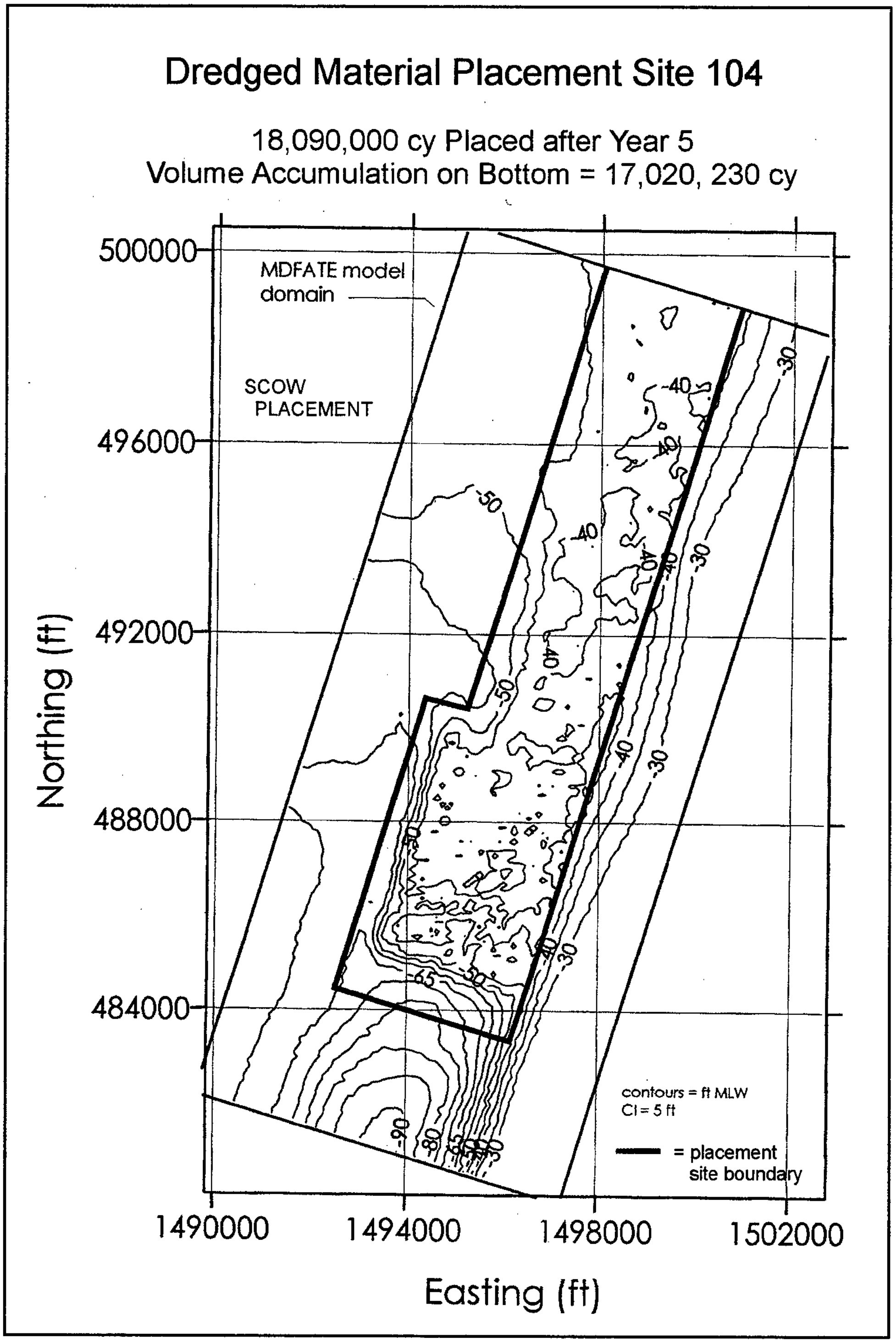


Figure 61. Site bathymetry after 5 years of barge placement

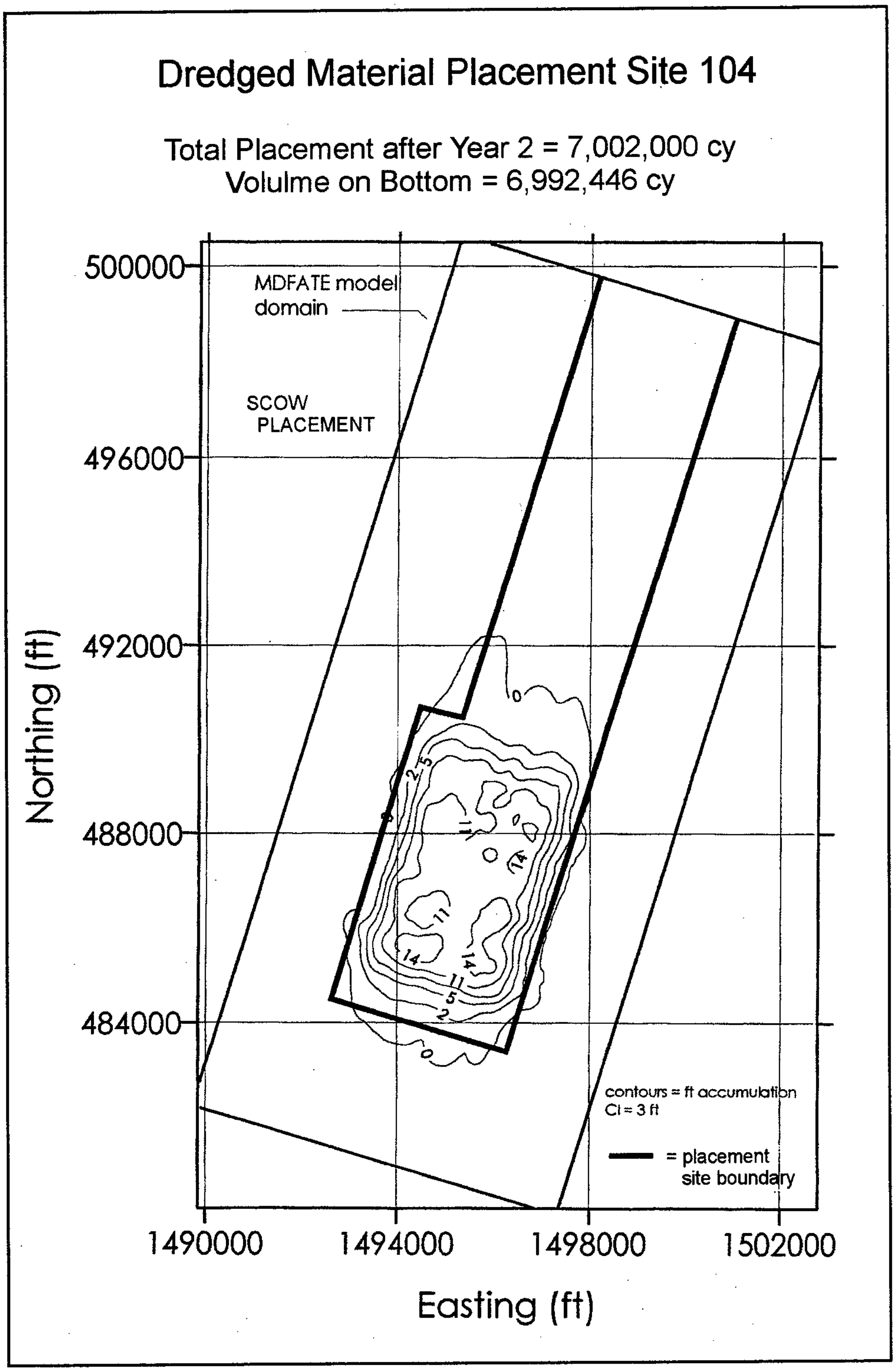


Figure 62. Cumulative deposition contours after 2 years of barge placement

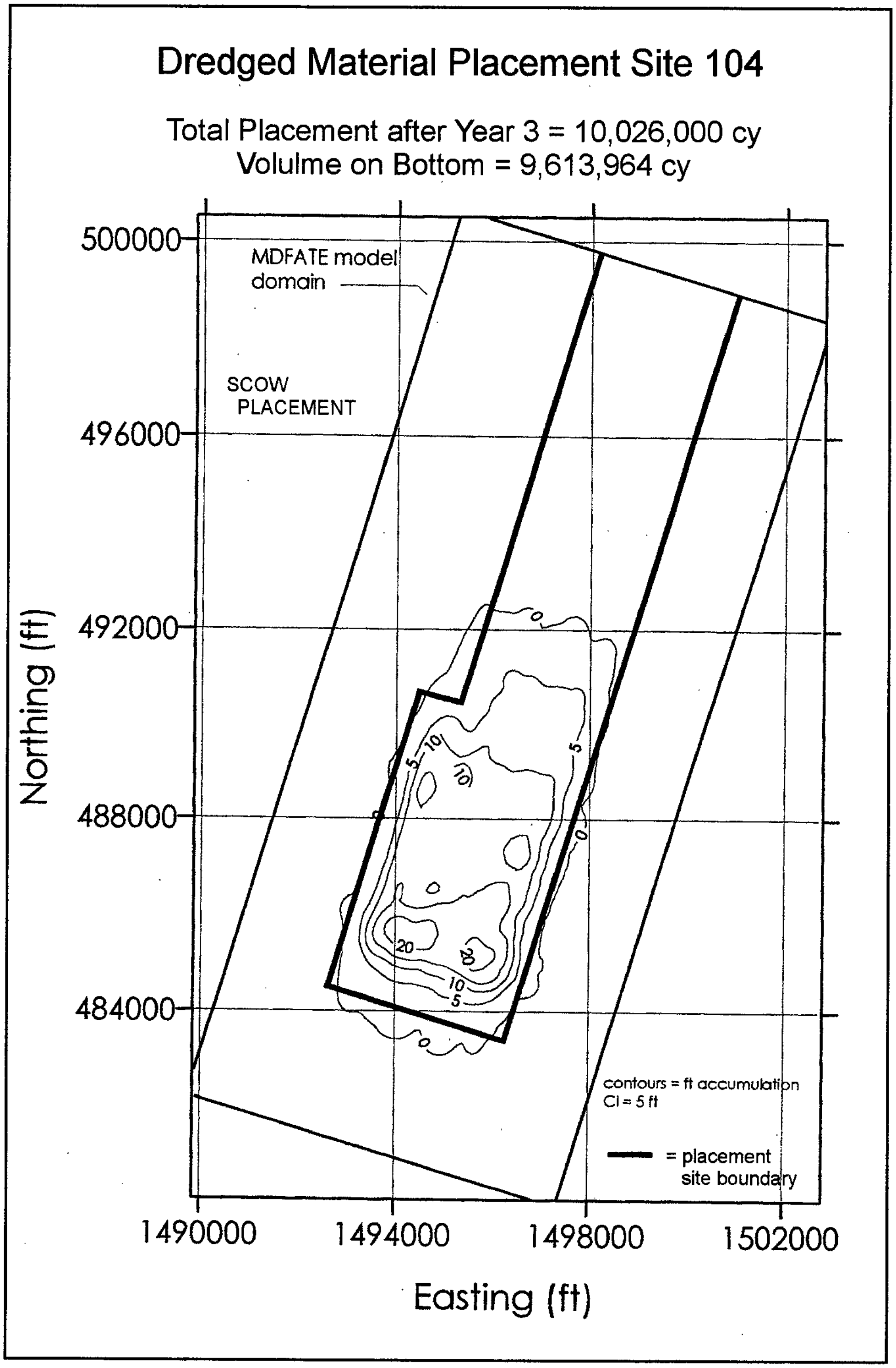


Figure 63. Cumulative deposition contours after 3 years of barge placement

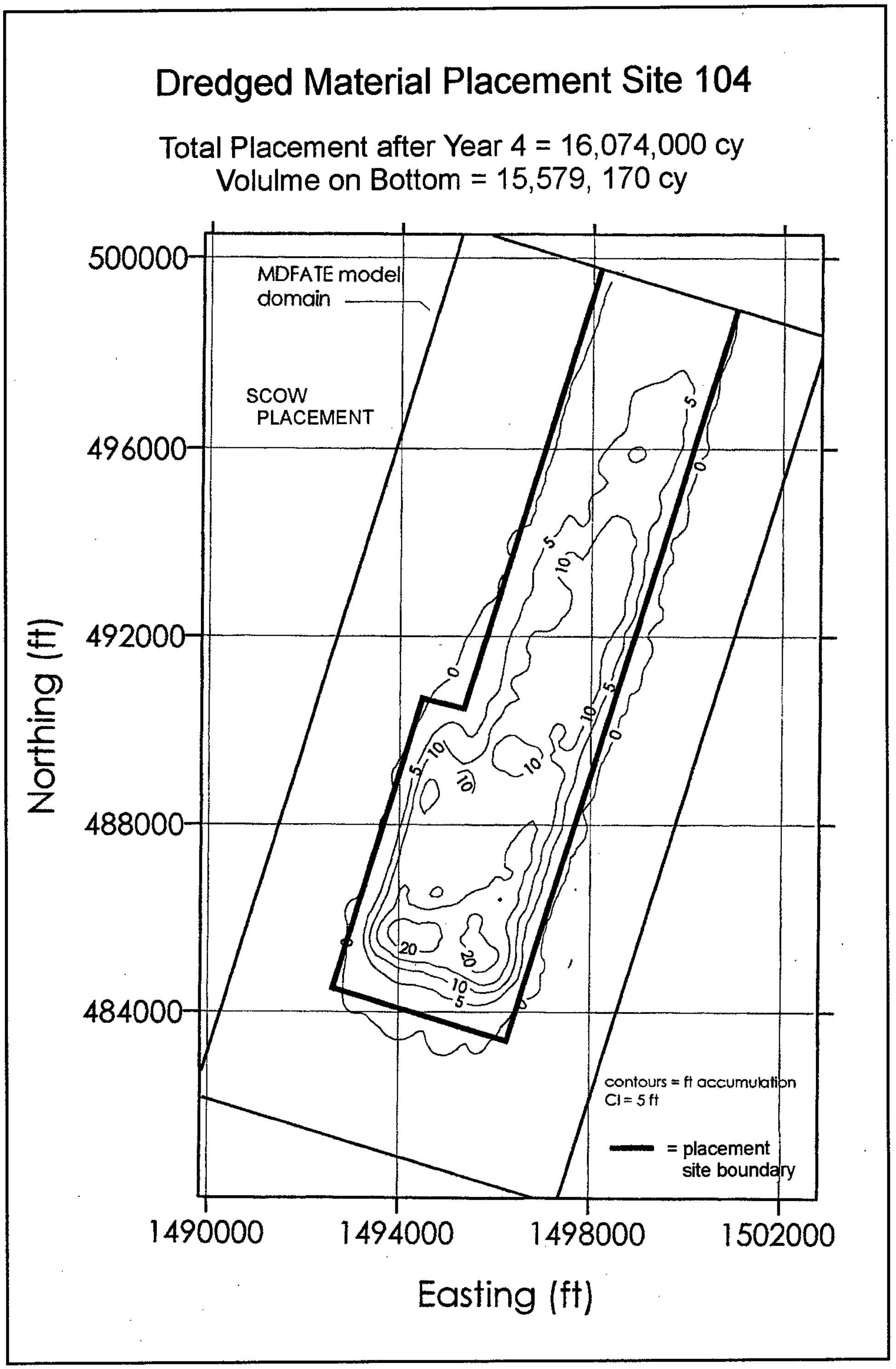


Figure 64. Cumulative deposition contours after 4 years of barge placement

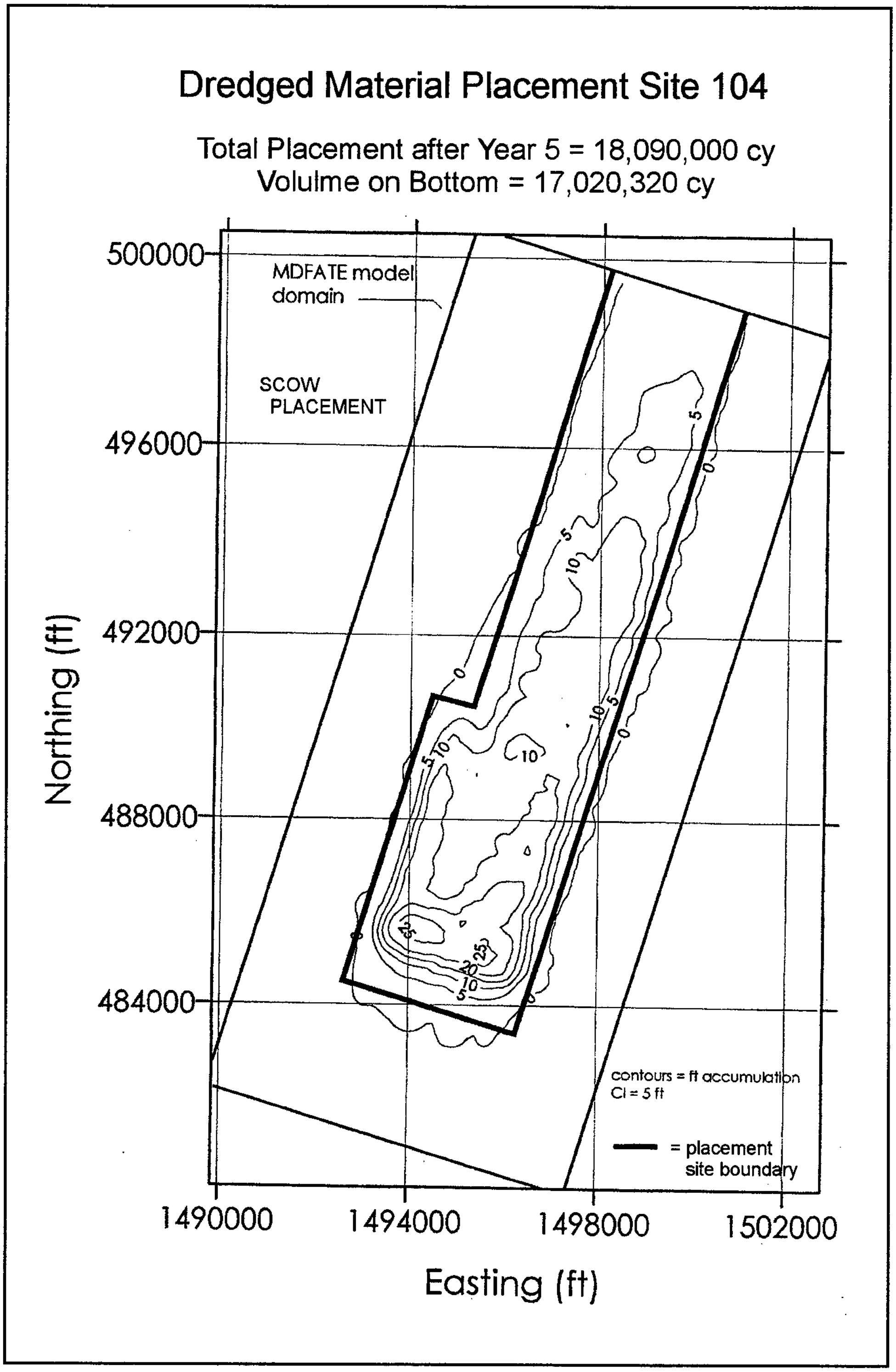


Figure 65. Cumulative deposition contours after 5 years of barge placement

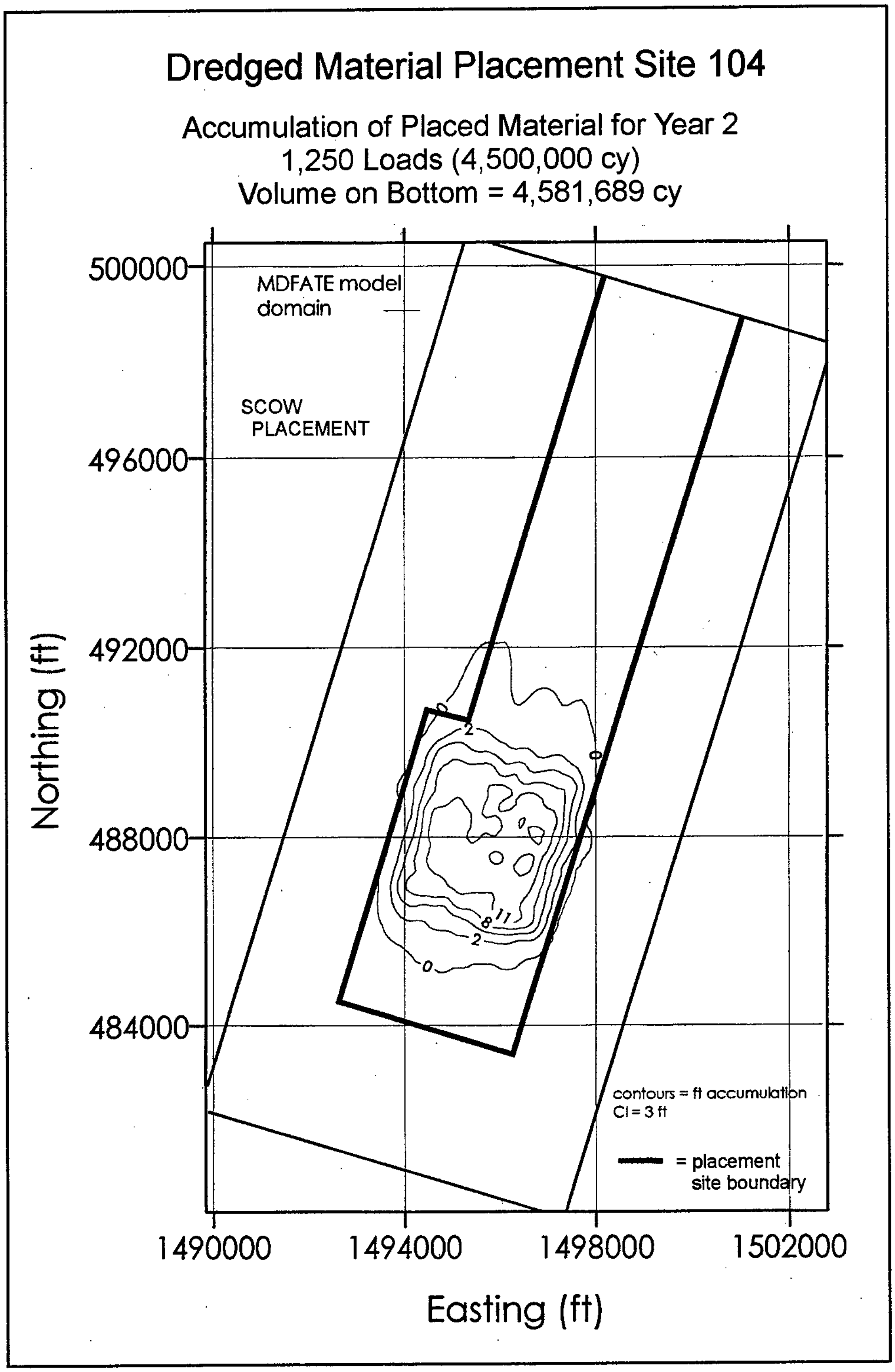


Figure 66. Deposition contours for only Year 2 of barge placement

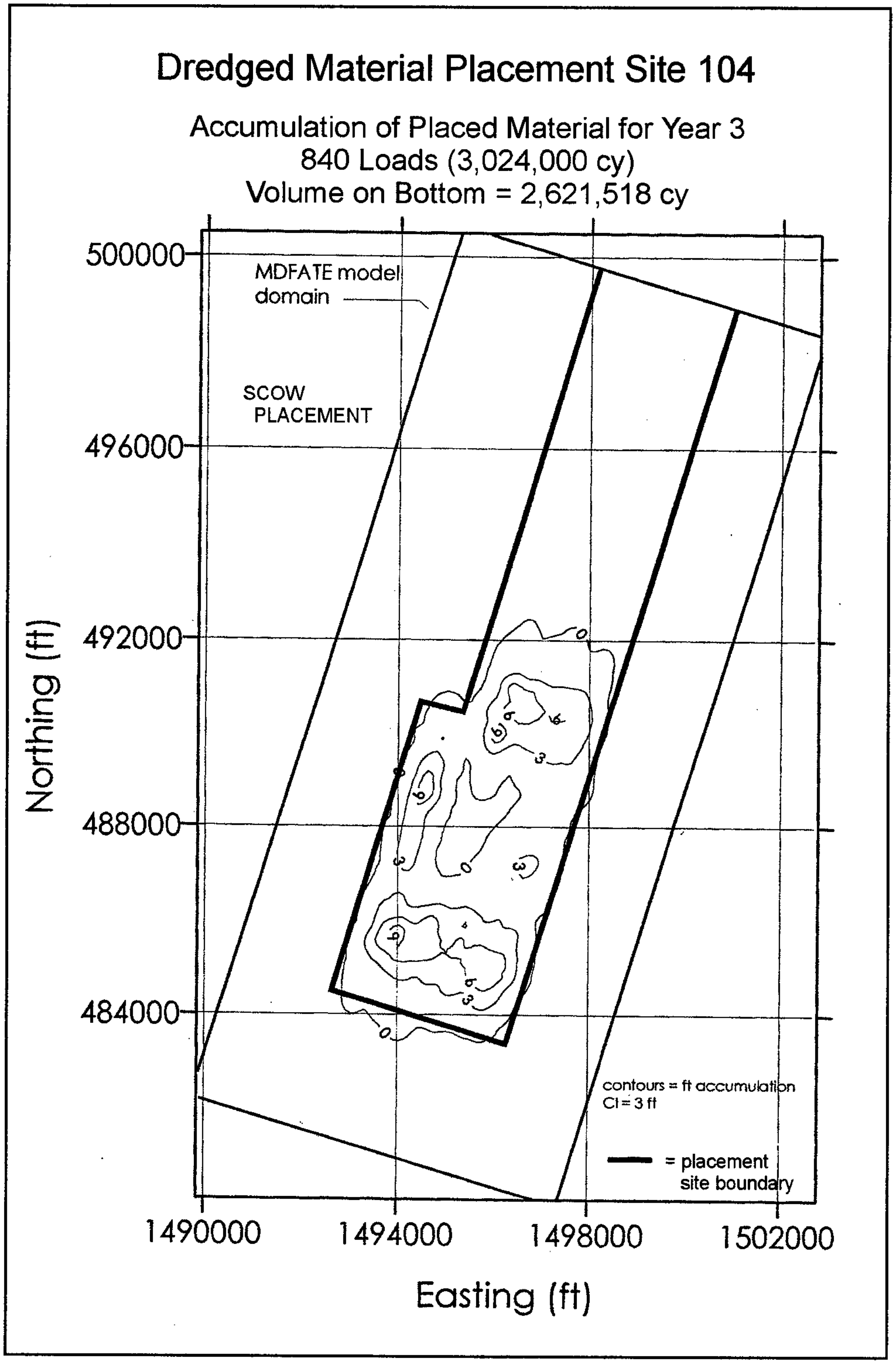


Figure 67. Deposition contours for only Year 3 of barge placement

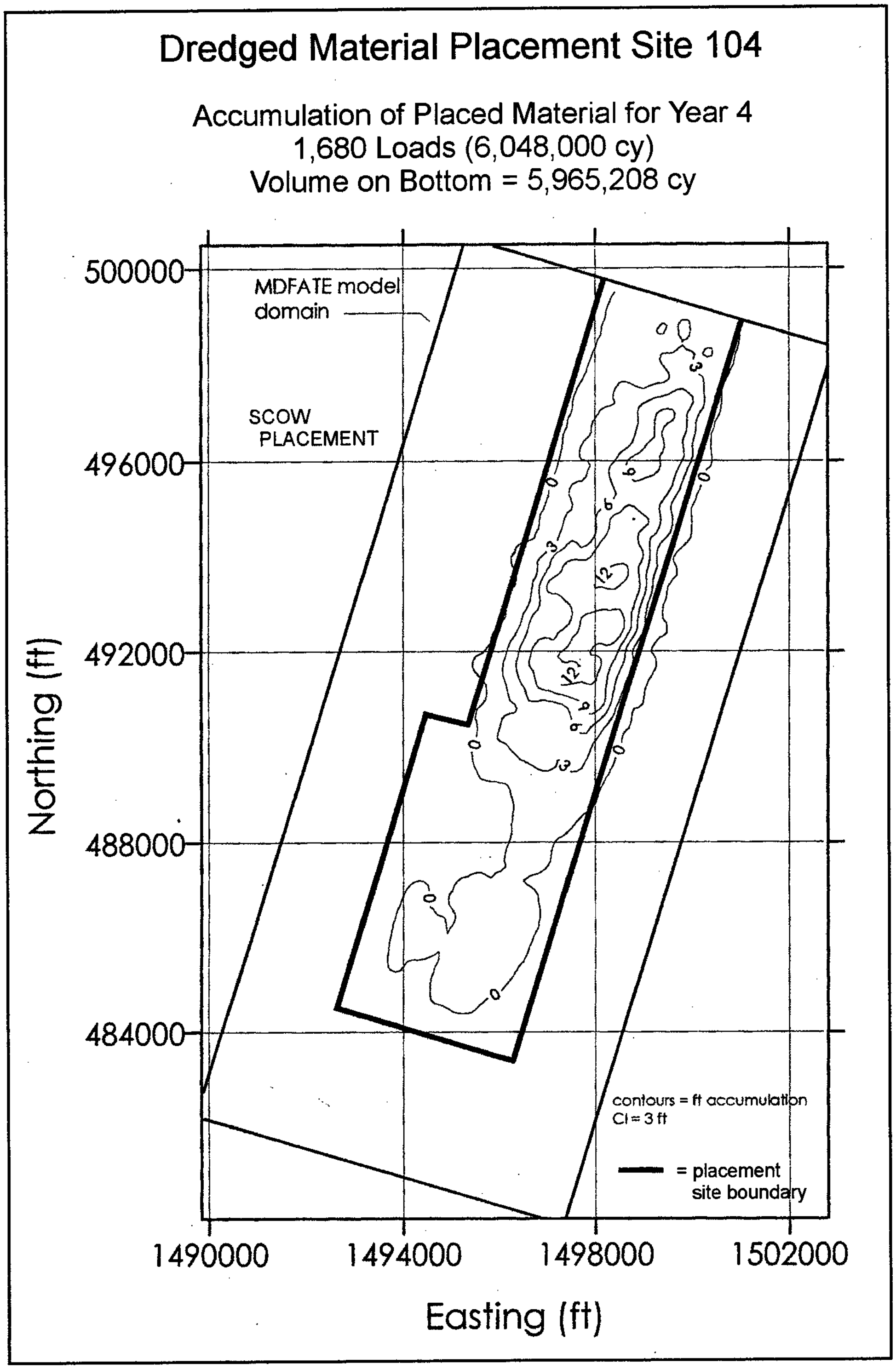


Figure 68. Deposition contours for only Year 4 of barge placement

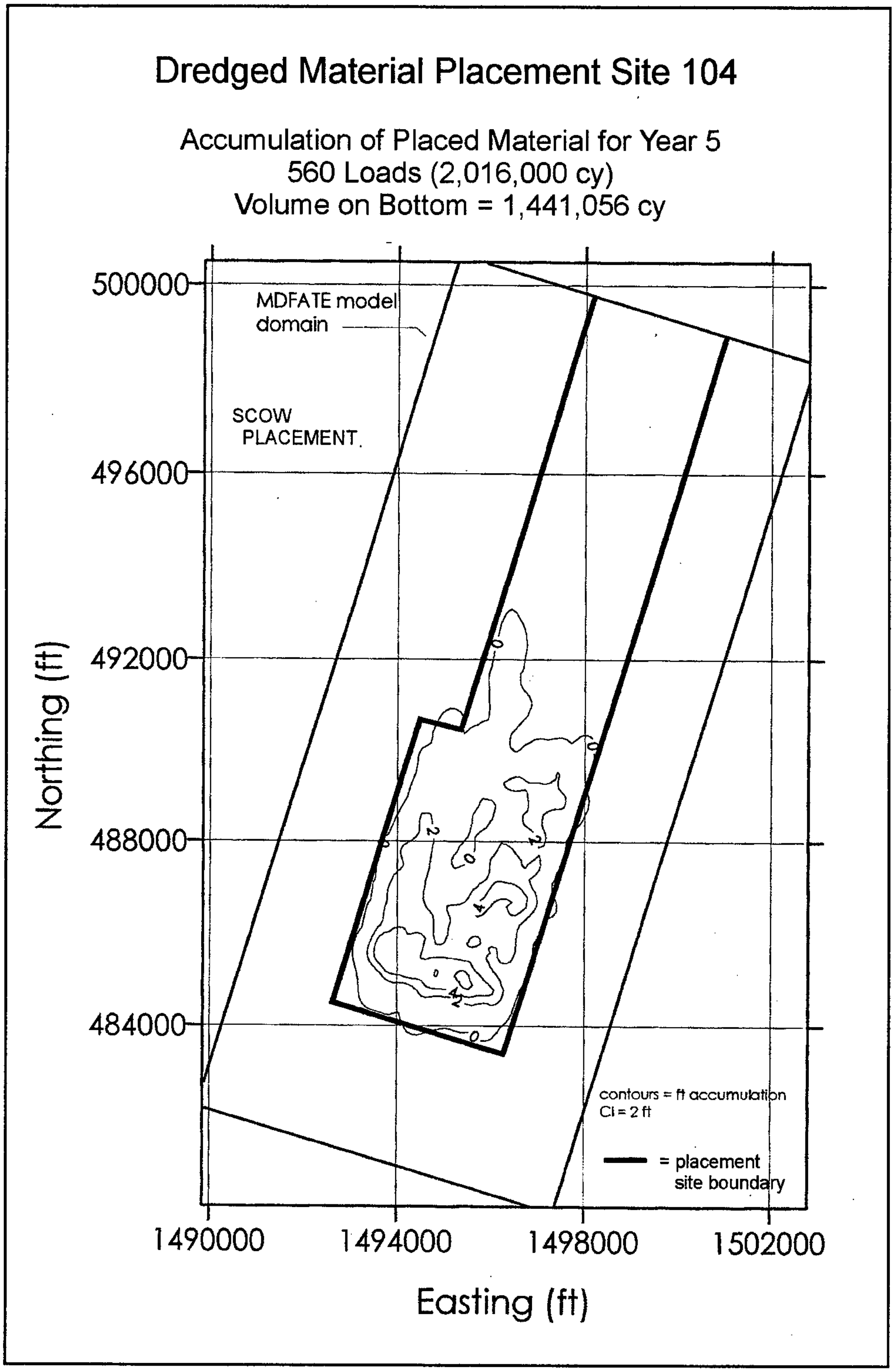


Figure 69. Deposition contours for only Year 5 of barge placement

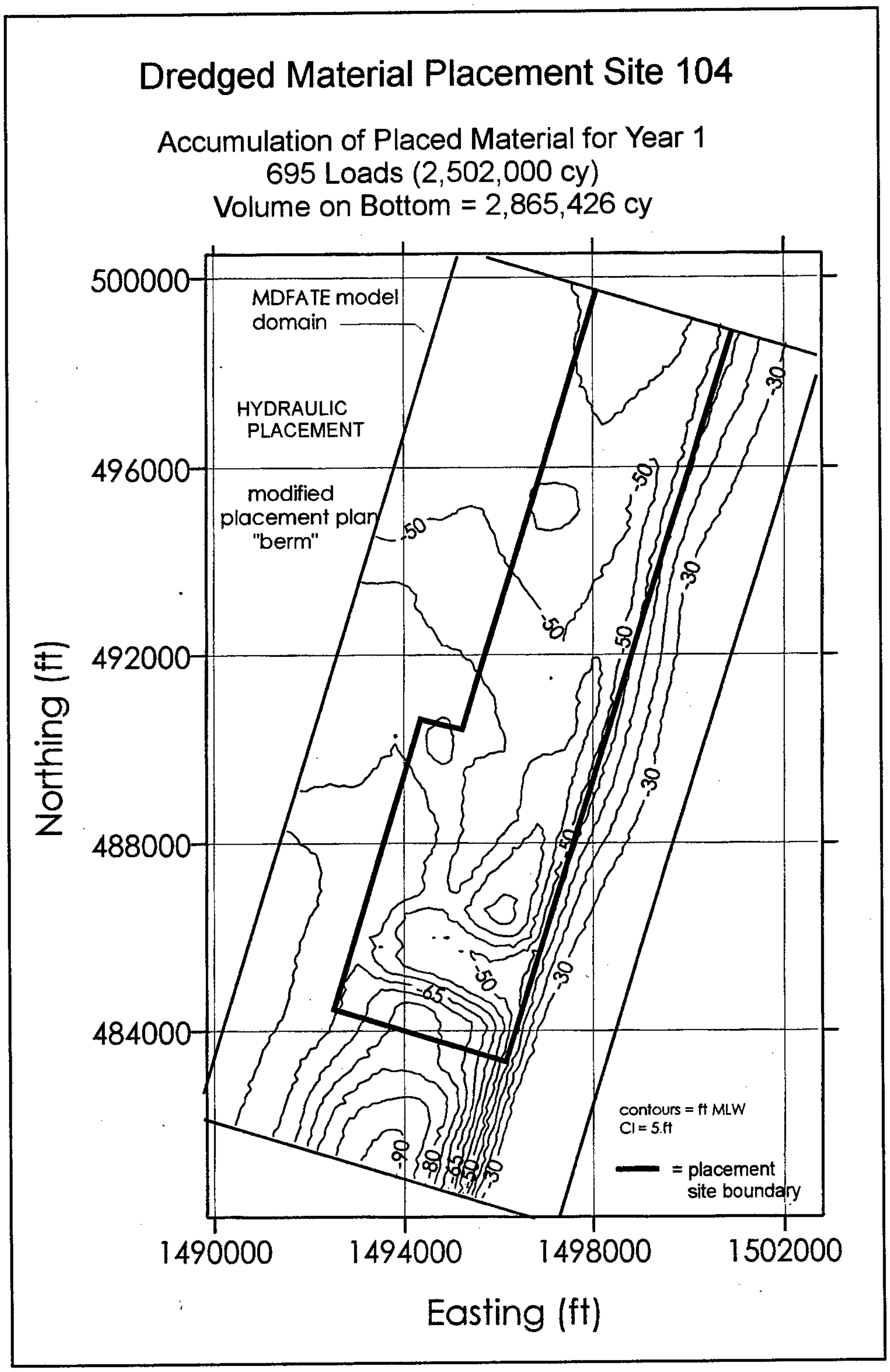


Figure 70. Site bathymetry after 1 year of hydraulic placement

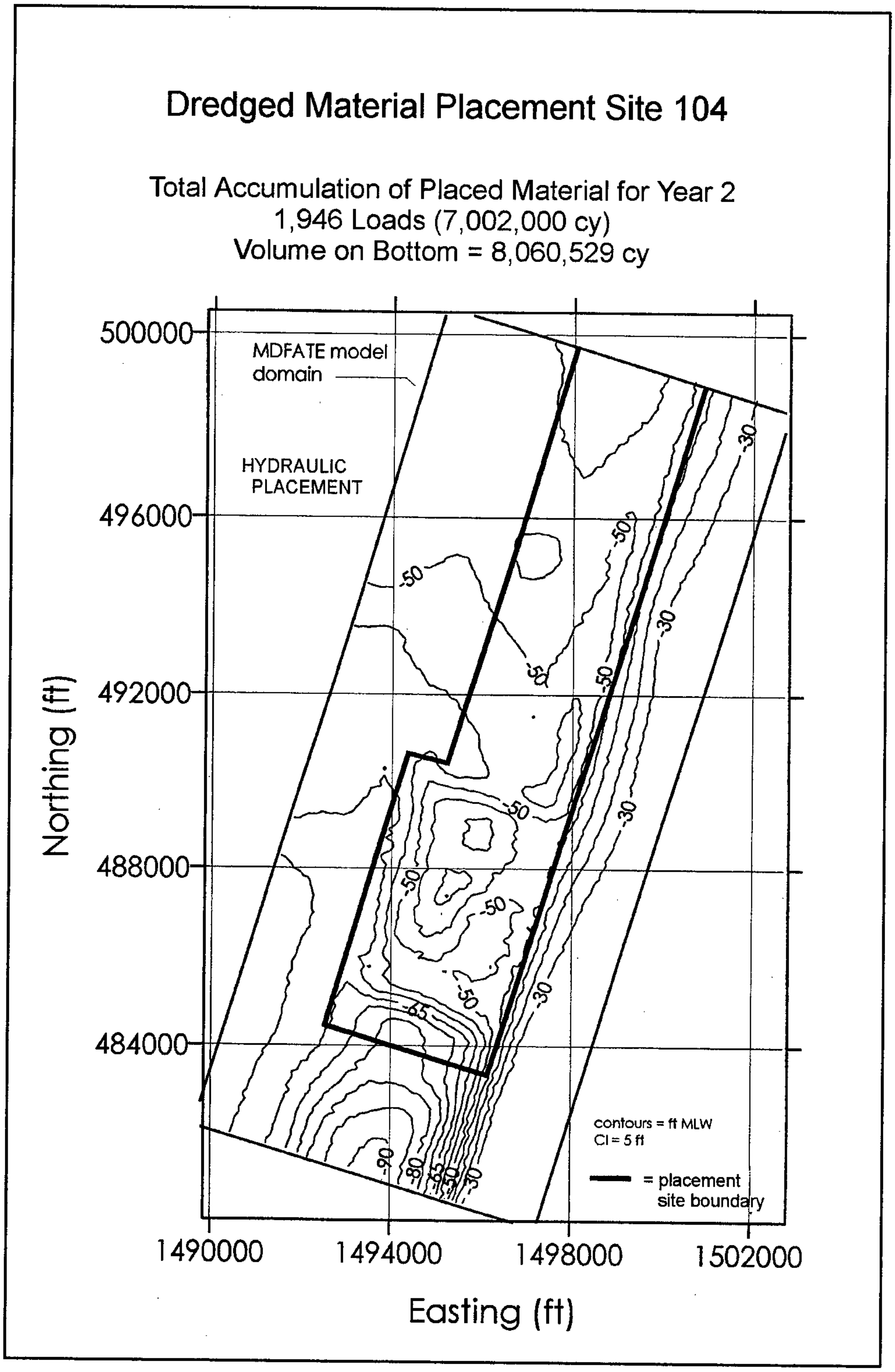


Figure 71. Site bathymetry after 2 years of hydraulic placement

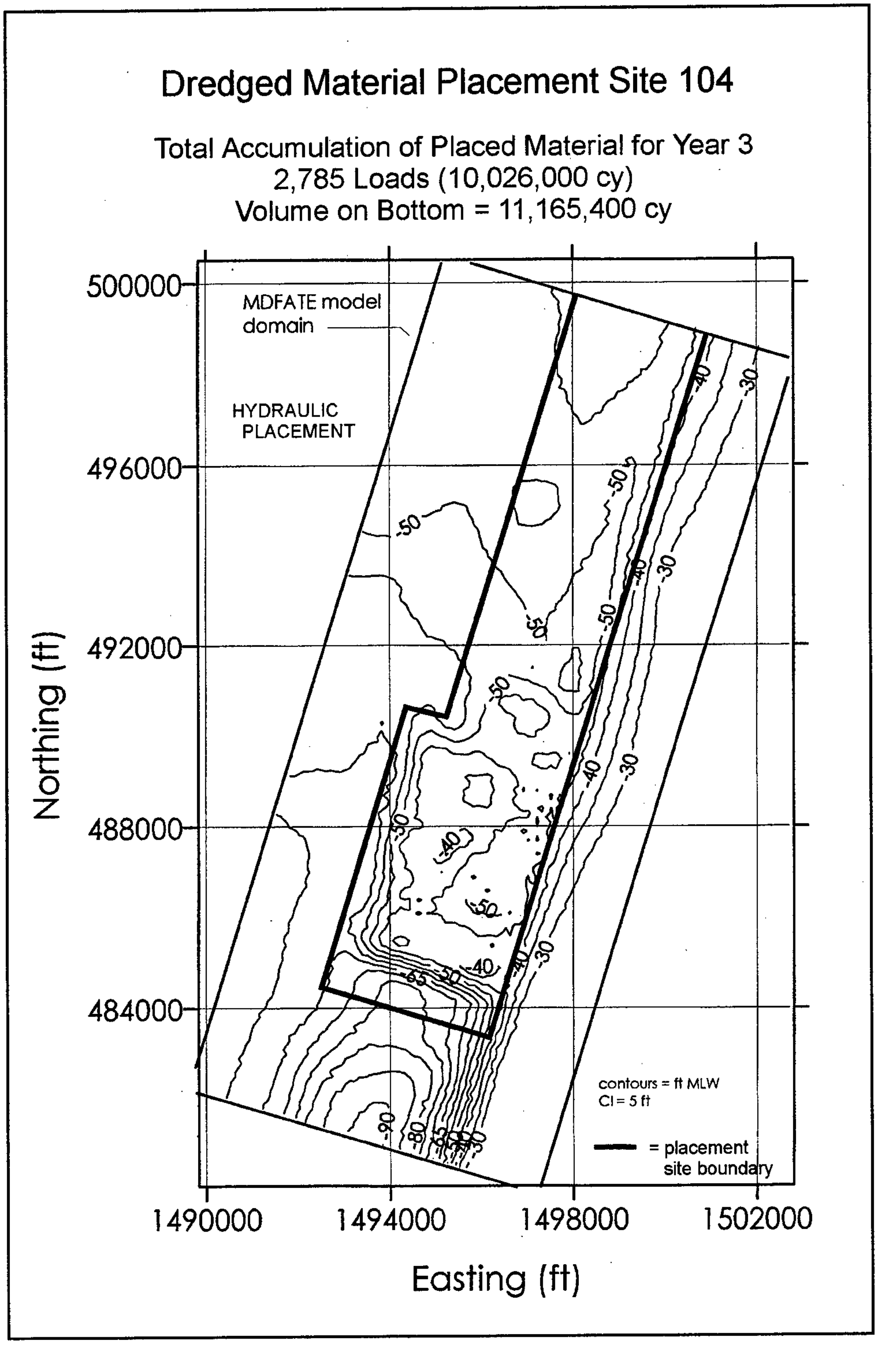


Figure 72. Site bathymetry after 3 years of hydraulic placement

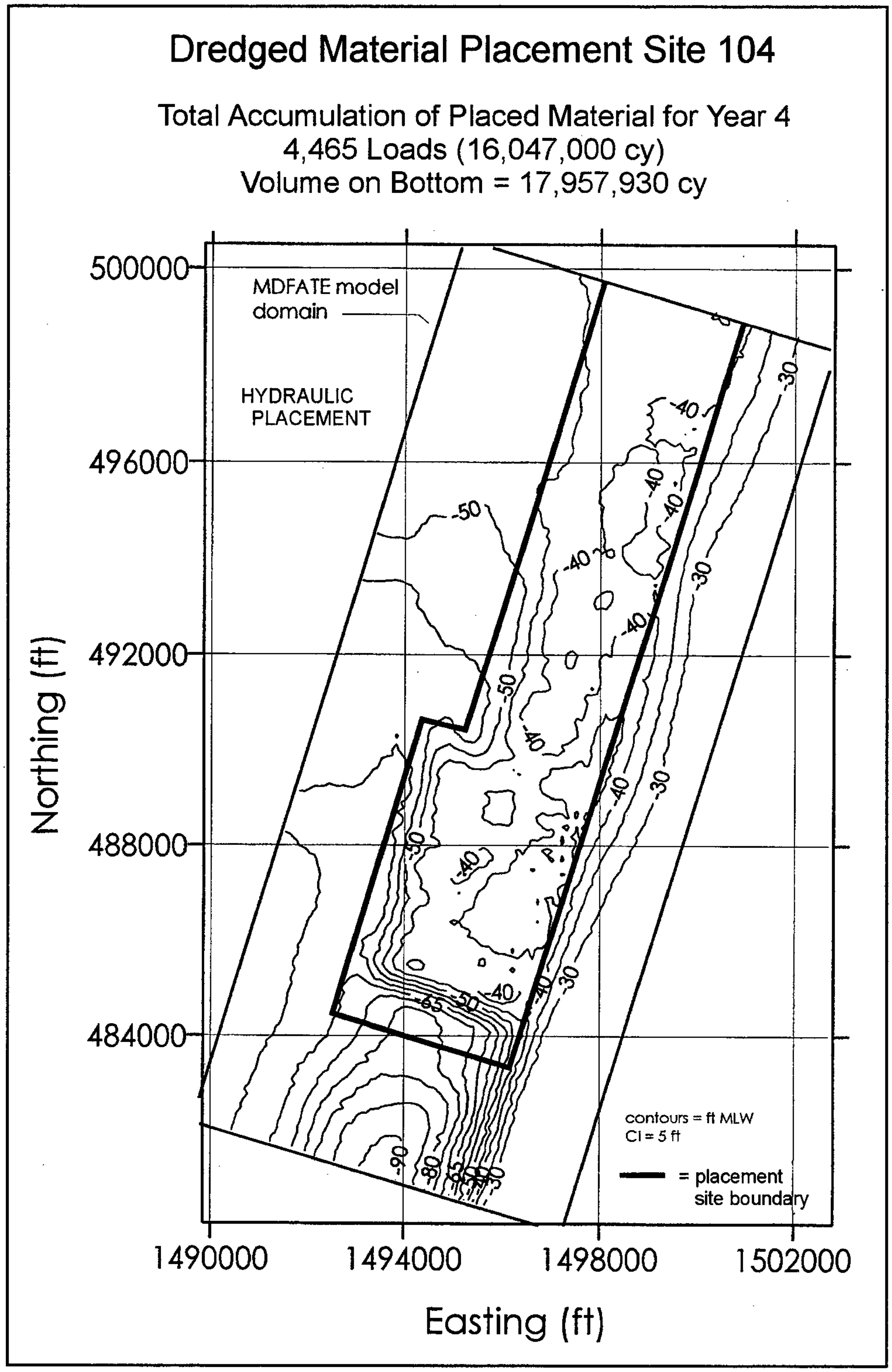


Figure 73. Site bathymetry after 4 year of hydraulic placement

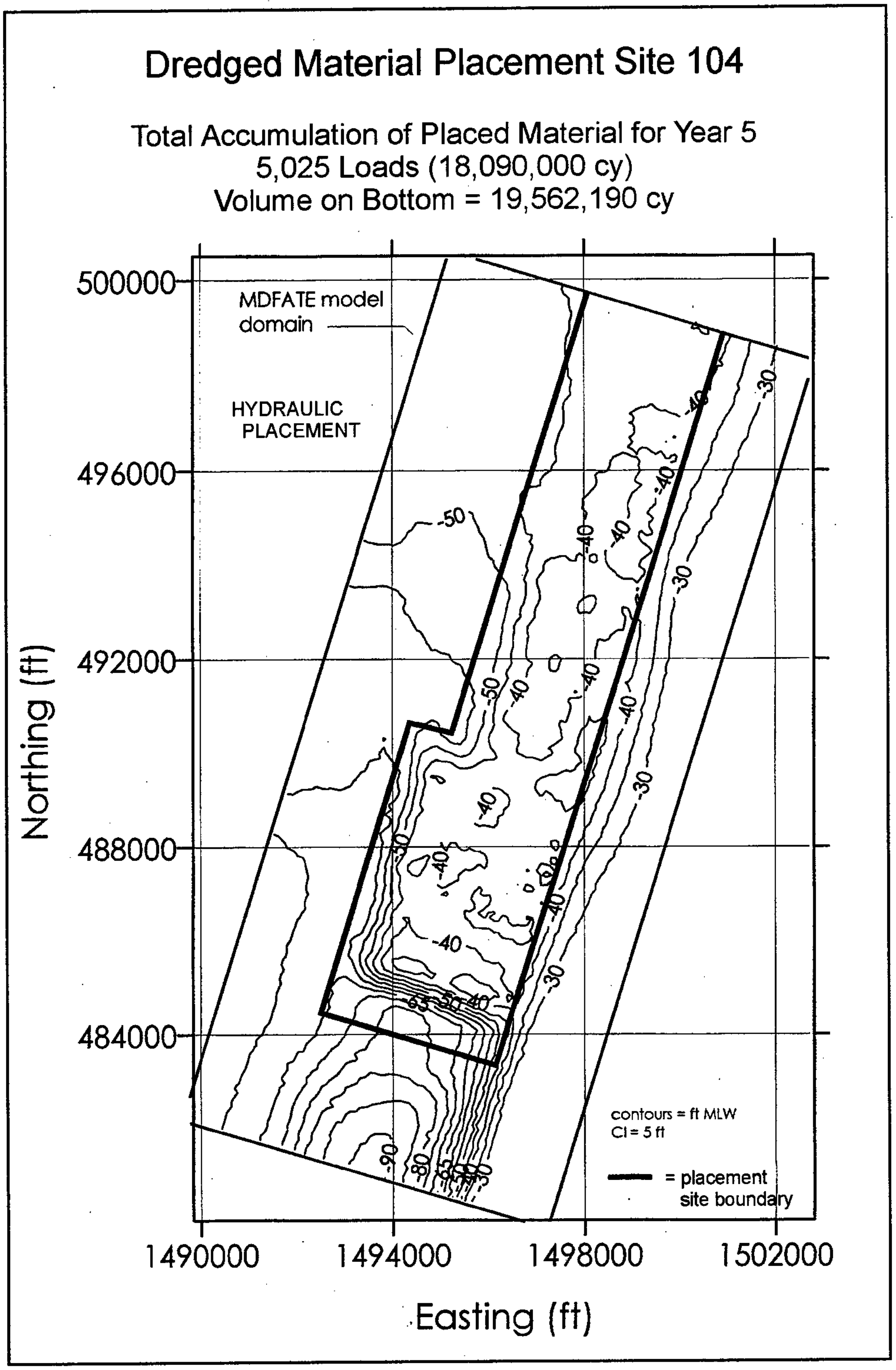


Figure 74. Site bathymetry after 5 years of hydraulic placement

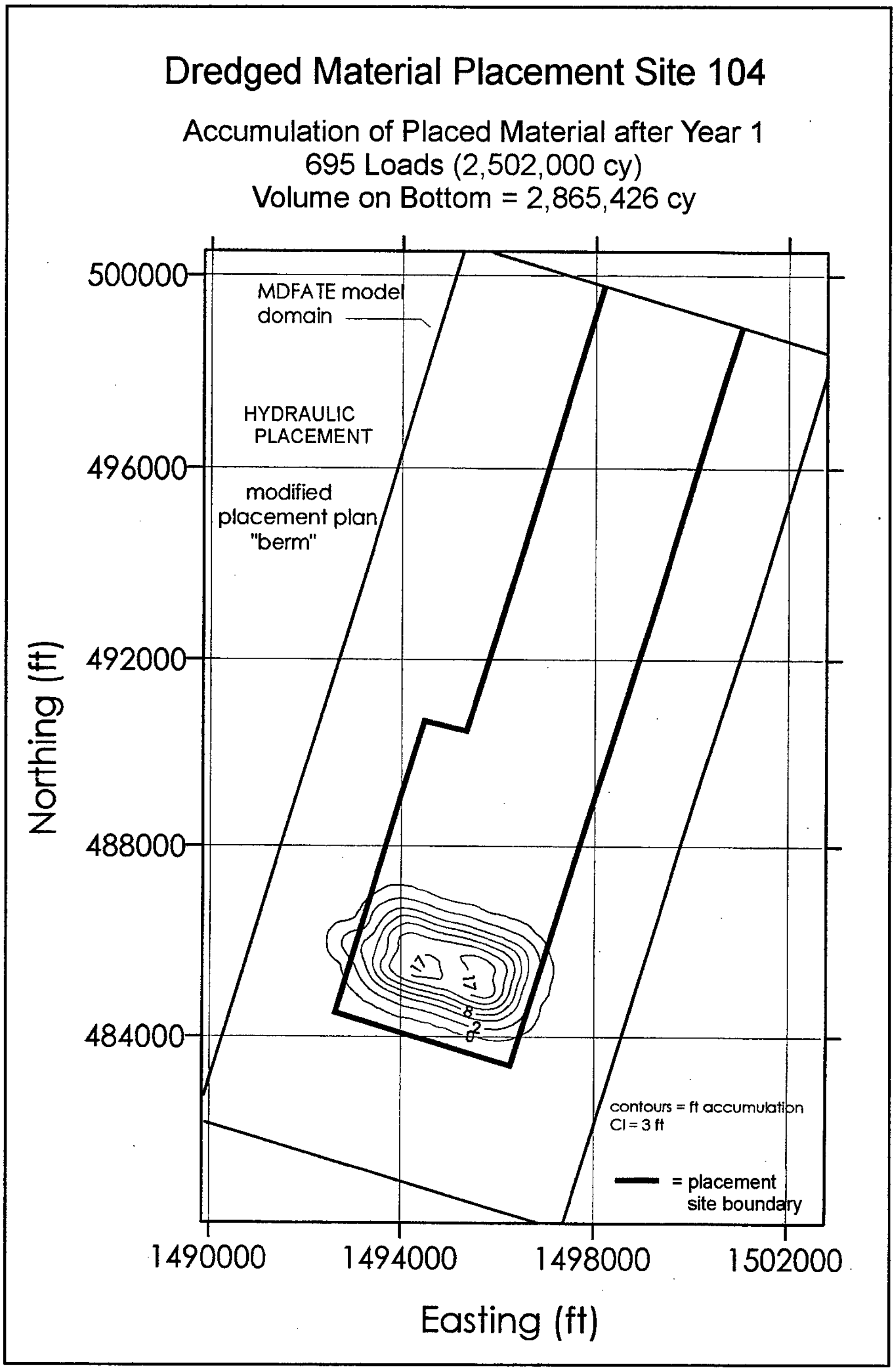


Figure 75. Cumulative deposition contours after 1 year of hydraulic placement

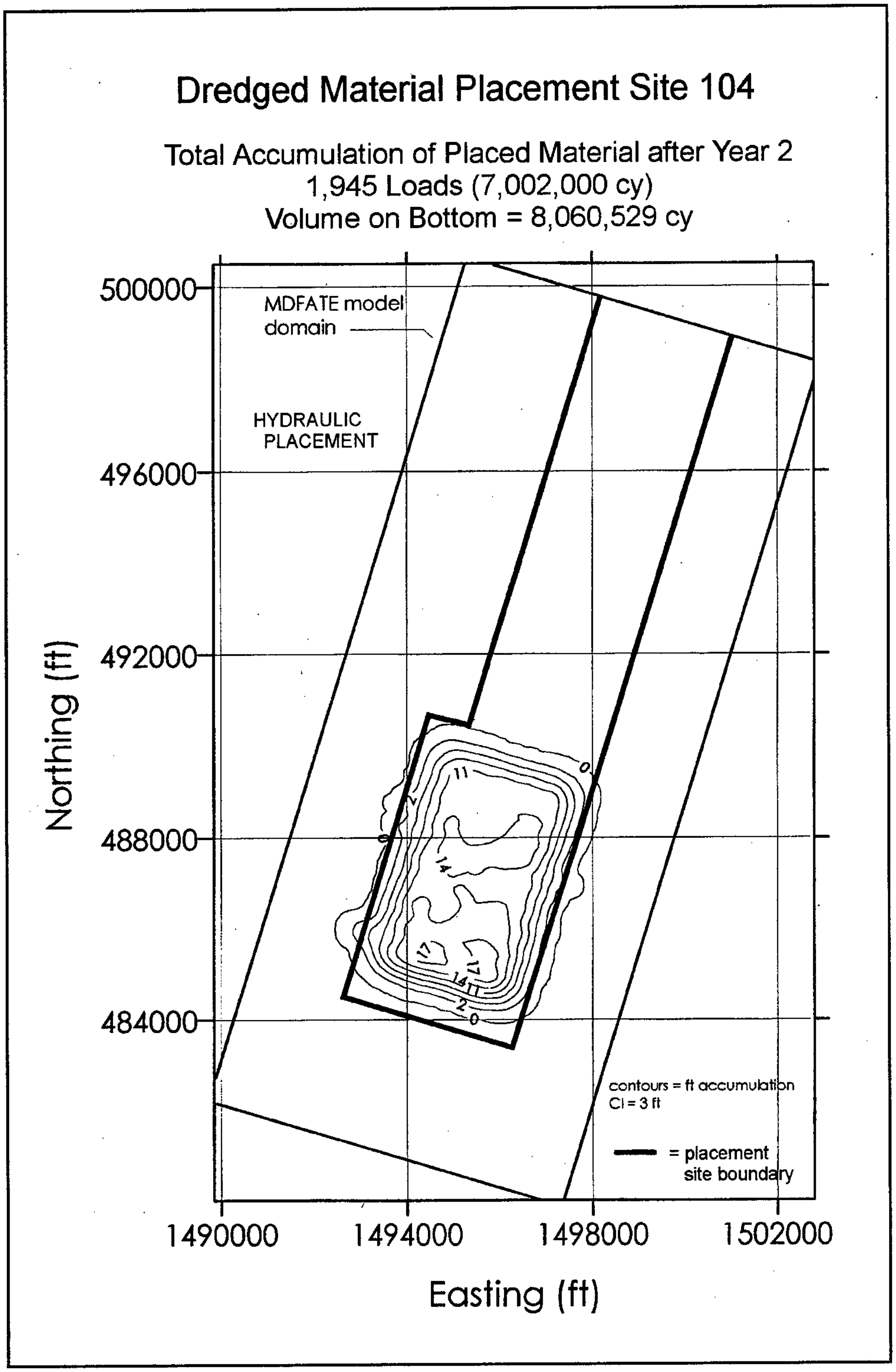


Figure 76. Cumulative deposition contours after 2 years of hydraulic placement

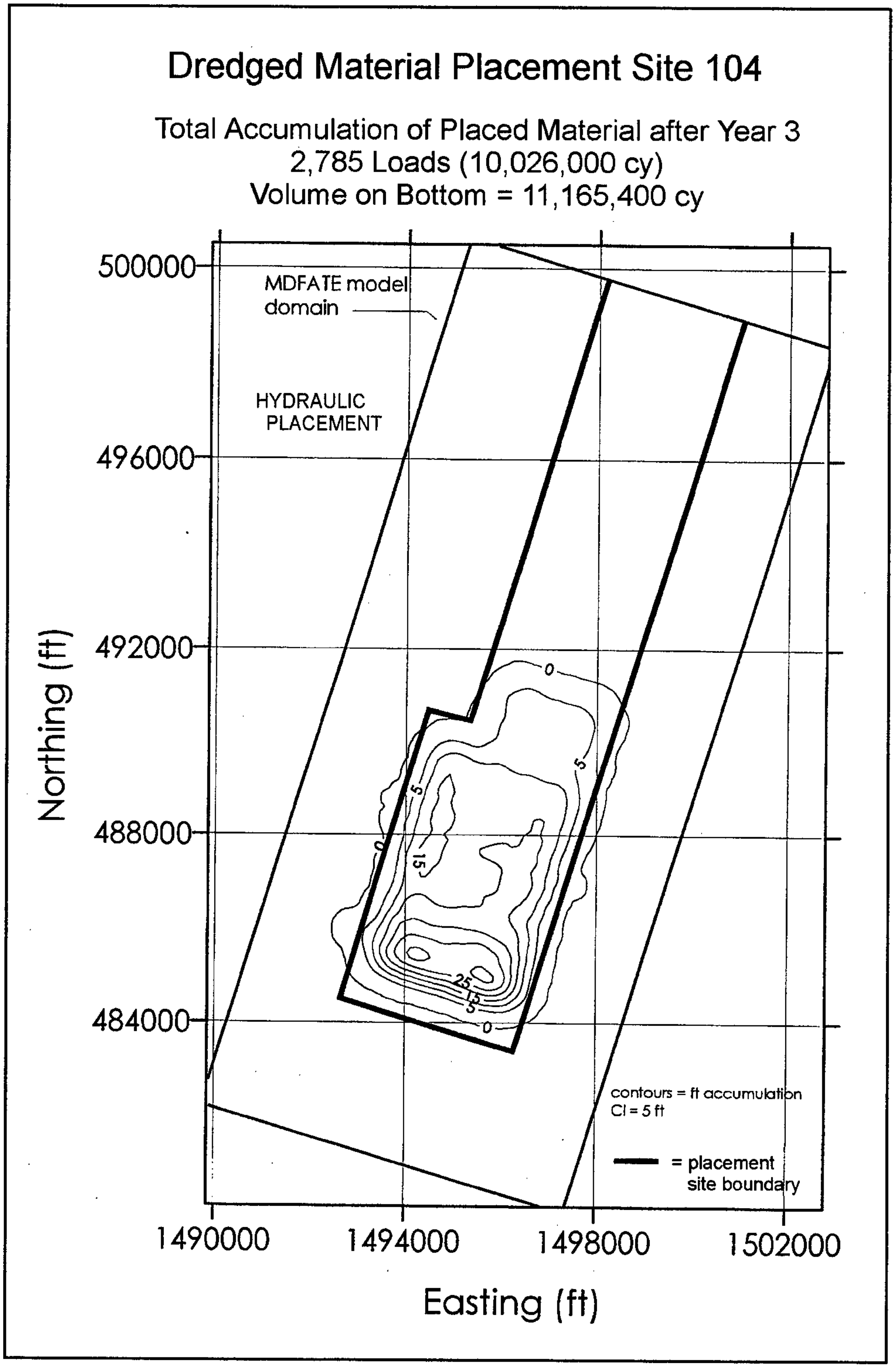


Figure 77. Cumulative deposition contours after 3 years of hydraulic placement

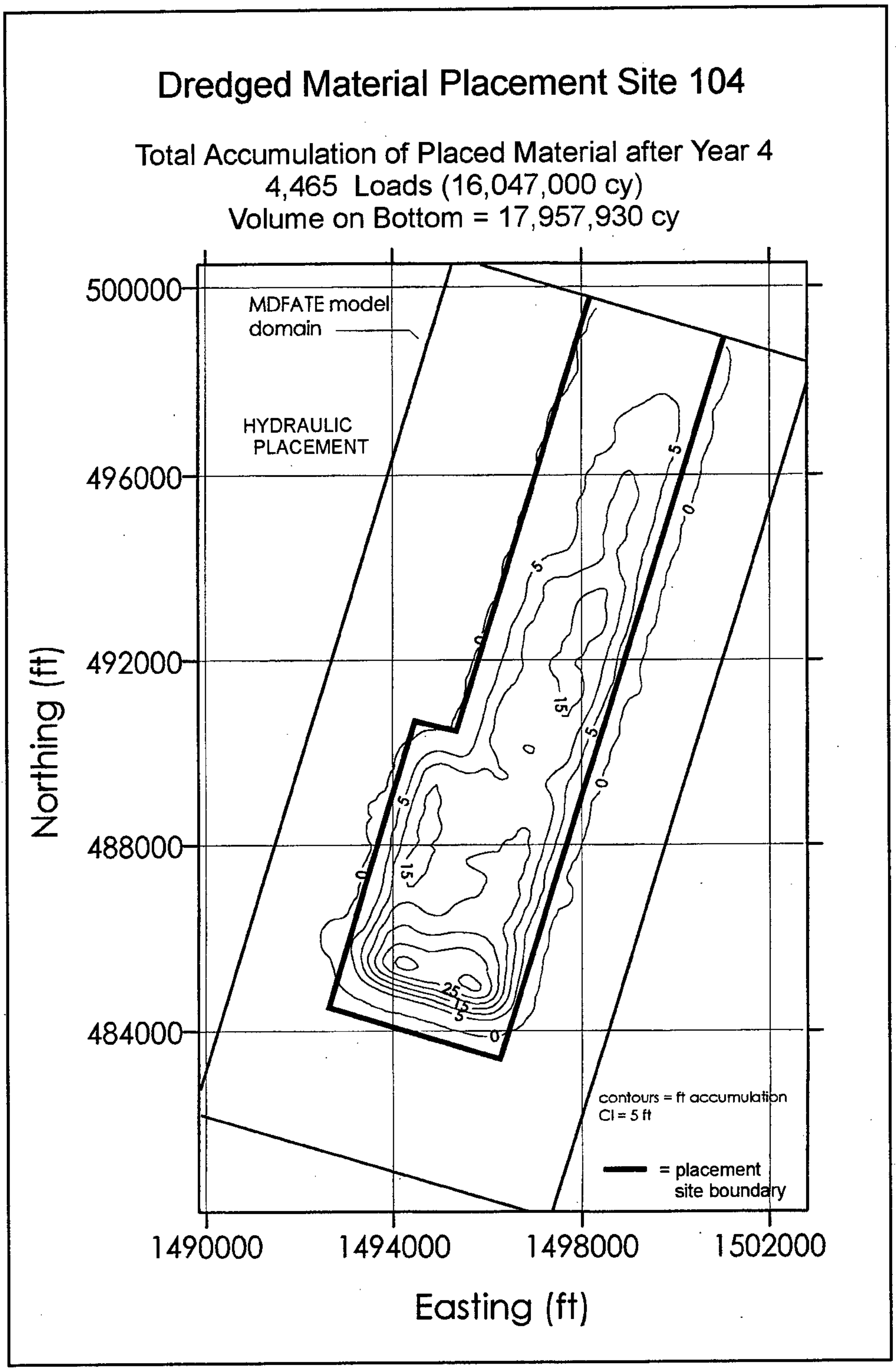


Figure 78. Cumulative deposition contours after 4 years of hydraulic placement

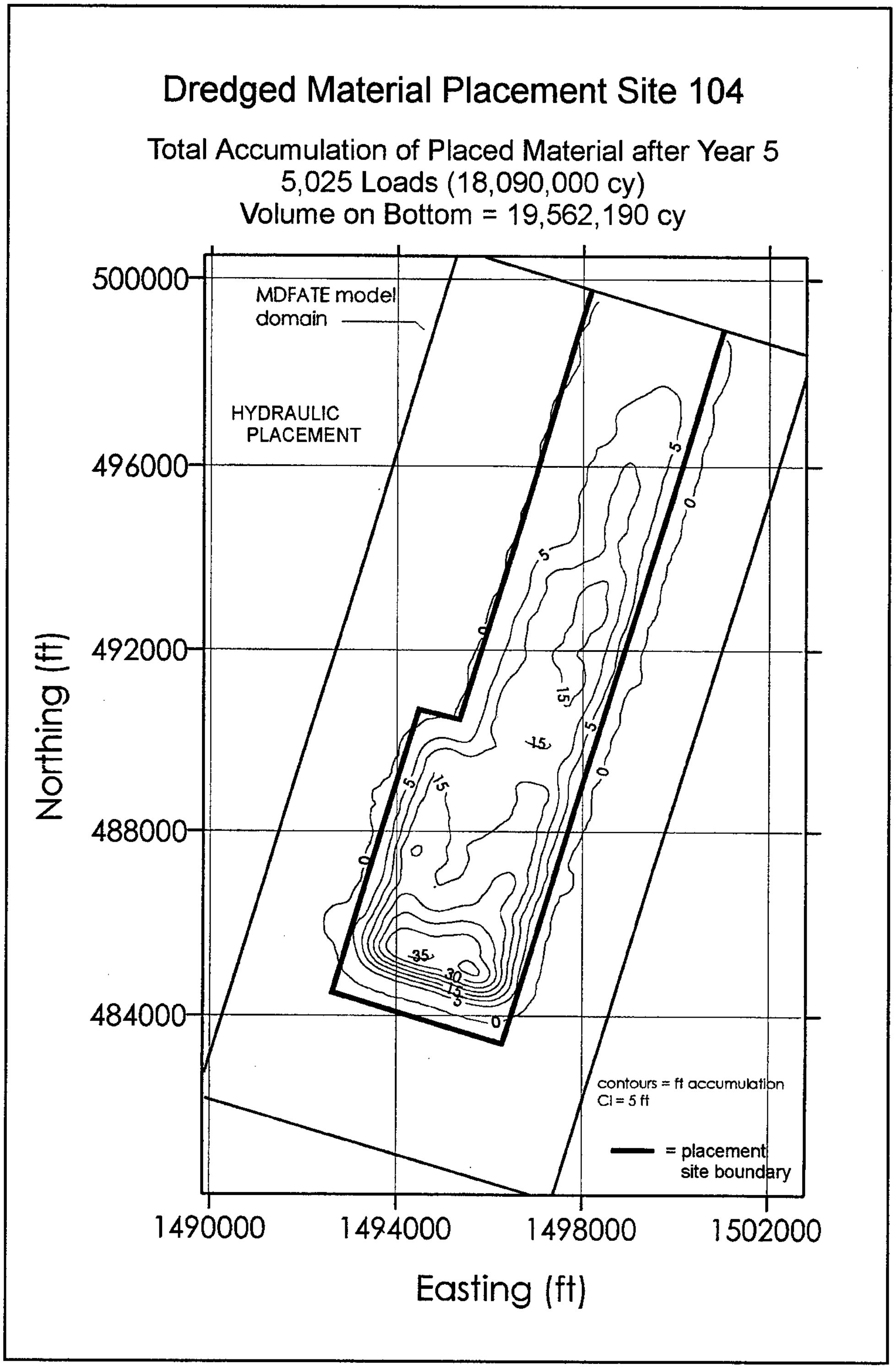


Figure 79. Cumulative deposition contours after 5 years of hydraulic placement

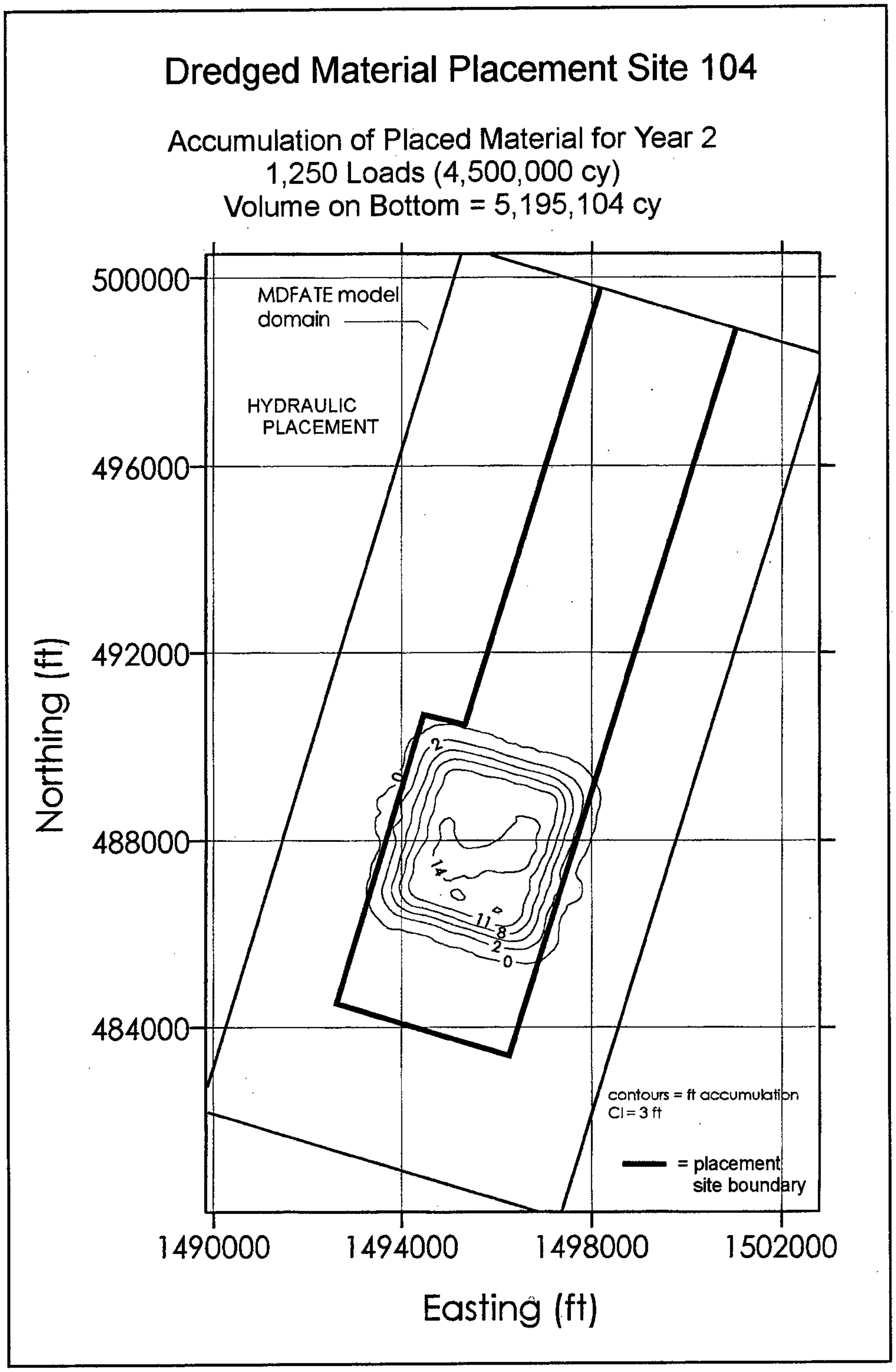


Figure 80. Deposition contours for only Year 2 of hydraulic placement

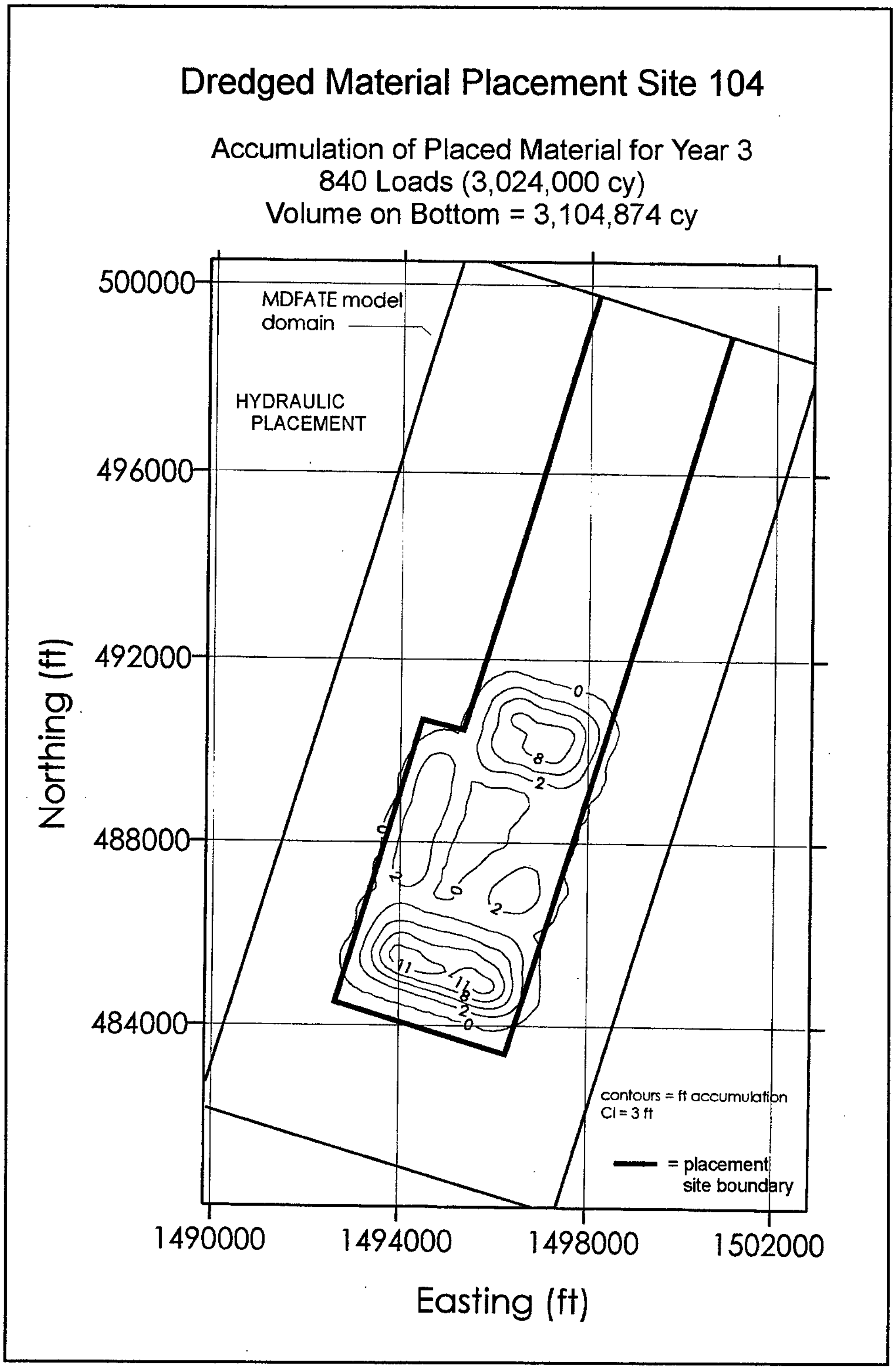


Figure 81. Deposition contours for only Year 3 of hydraulic placement

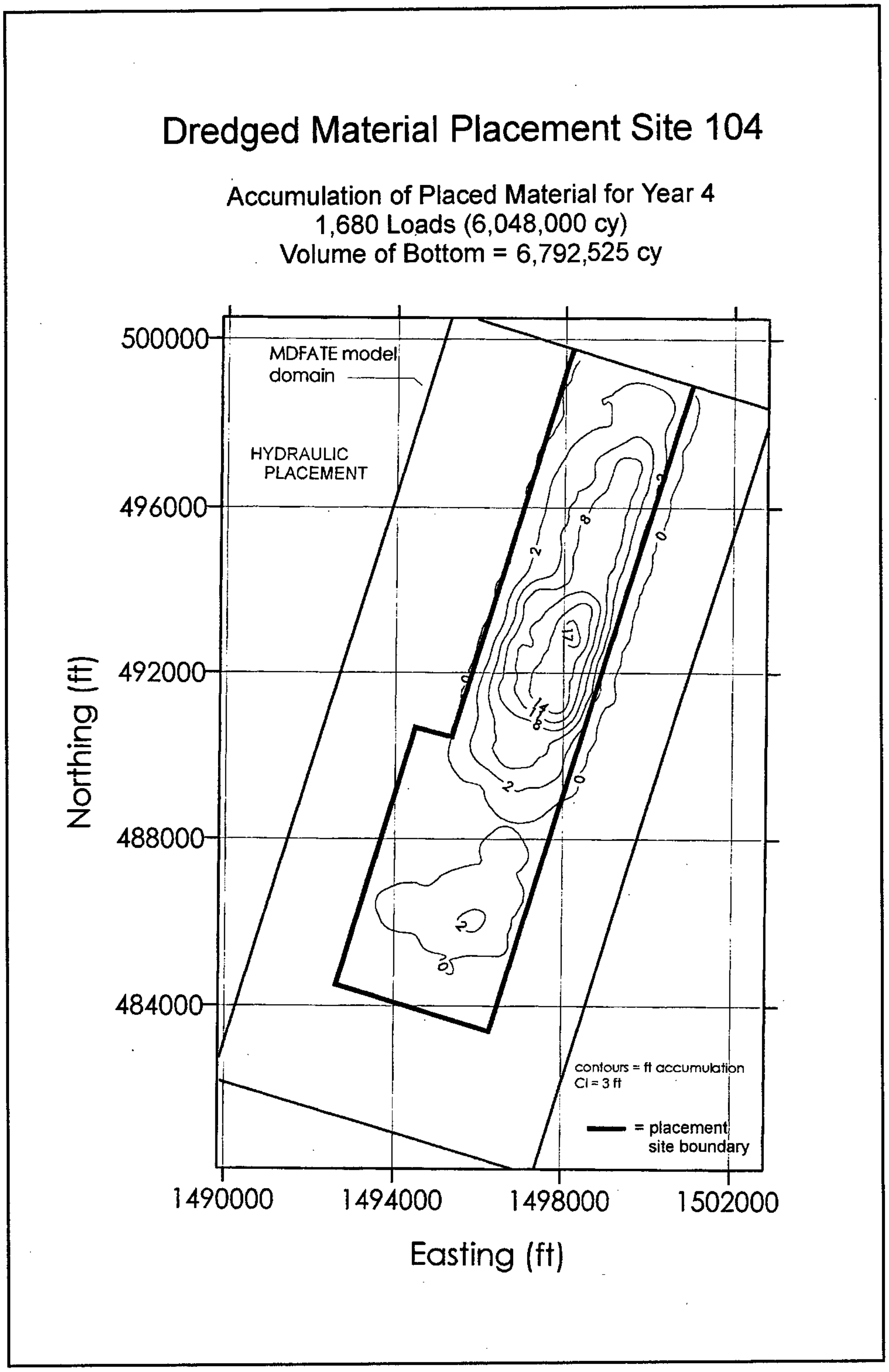


Figure 82. Deposition contours for only Year 4 of hydraulic placement

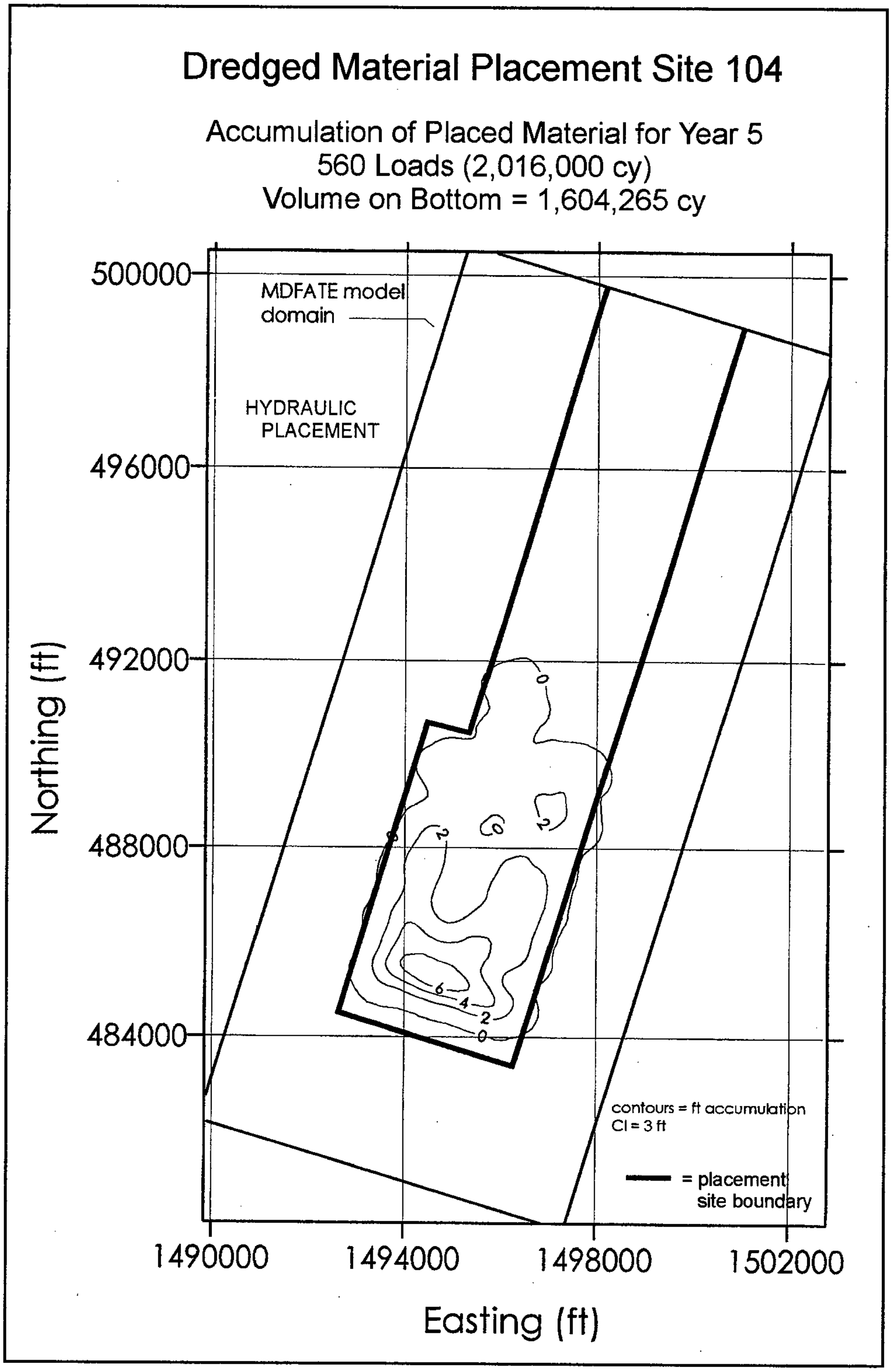


Figure 83. Deposition contours for only Year 5 of hydraulic placement

10 Water Quality Simulations

As part of the Site 104 study, the water quality impacts of proposed dredging operations in upper Chesapeake Bay have been examined. As previously noted, dredging is currently planned to take place over a period of 5 years with operations restricted to the period from 15 October through 15 April. Volumes placed during each dredging season are listed in Table 1.

The investigation employed the 3-D Chesapeake Bay water quality model previously discussed. The model code and parameter values were identical to the model used in the 1992 reevaluation of nutrient reduction strategy (Cerco and Cole 1994). The grid, however, is a revised grid containing roughly 10,000 cells and presently employed in the tributary-refinements portion of the Chesapeake Bay water quality model study. Grid refinements were primarily made in the lower bay tributaries. At present, 3 years of hydrodynamics (1985-87) are available to drive water quality computations. Since dredging operations are proposed for 5 years, a synthetic sequence of years 1985, 1986, 1987, 1985, and 1986 was created. Loads and boundary conditions corresponding to the hydrodynamic sequence were employed. With the water quality model running from 1 January 1985 for 5 years, only part of the first year of dredged material could be placed at Site 104, and only part of the fifth year of dredged material could be placed. The total volumes listed in Table 1 for Years 2, 3, and 4 were placed at the site. One should note that, unlike the MDFATE simulations, the hydrodynamics are computed only for the existing bathymetry, i.e., the effect of the site being filled is not reflected. Although filling the site does modify the hydrodynamics, Figures 27-36 illustrate that the change is small. Thus, the impact of using hydrodynamics based on the initial bathymetry is not significant in the water quality model.

The water quality model operates by dividing the continua of space and time into discrete grid cells and time steps. These discretizations represent the minimum resolution of the model. The grid cell containing Site 104 is 3.39 by 4.17 km, whereas, the site dimensions are actually 1.1 by 6.8 km. The average water depth of the cell covering Site 104 is 55 ft. The cell just south of the Site 104 cell has a depth of 65 ft, and the cell just to the north has a depth of 45 ft. These are representative of the existing bathymetry. Model time steps are 15 min. This time scale is forced by numerical stability requirements. Even though model computations are made at small time intervals, only predictions that are averaged over time scales of a day or more are meaningful.

One feature of the water quality model of particular relevance to this investigation is a fully predictive benthic sediment diagenesis model. The model was used to provide information on characteristics of the dredged material and to predict how newly deposited dredged material would interact with the water column.

Limiting Approaches

In one placement approach, dredged material will be released from the bottom of a barge or scow. After the material strikes the bottom and the resulting surge energy is dissipated, particulate matter remaining in the water column over the bottom 3-4 m is expected to settle rapidly to the bottom. While the material settles, substances dissolved in interstitial water, and sediment-sorbed particles may be released to the water column through the process of elutriation. In the second approach, material will be pumped from the barge and placed on the bottom. In this case, the assumption is that there will be no suspended material in the water column. However, as previously noted, in reality some material will likely be suspended in the water column. Experiments conducted on various dredged materials (Jones and Lee 1978) indicate that elutriation of some substances (e.g., ammonium) may be nearly 100 percent, while for other substances (e.g., phosphate), only a small fraction is lost to the water. Apart from these general guidelines, no exact experimental data were available for the material to be placed at Site 104.

The water quality simulations conducted bound the problem. In the first approach, complete elutriation was assumed. All ammonium, nitrate, phosphate, and chemical oxygen demand (COD) associated with the dredge material was released to the water column while particulates were deposited on the bottom. Release was to two model layers corresponding to the lower 3 m of the water column. In the second approach, no elutriation was assumed. All particulate and dissolved substances contained in the dredge material were placed directly on the bottom at Site 104.

Properties of benthic sediments computed by the model at the dredged sites were examined and used to create an average composite sediment (Table 17). This composite sediment was deposited directly on the bottom for the "no elutriation" run. Placement of material was imposed only during the November through March period in which dredging operations were assumed to occur. For the "complete elutriation" run, dissolved and sorbed substances were released to the water column at rates shown in Table 18. Particulate organic matter was deposited directly on the bottom as in the "no elutriation" run.

A comparison of model sediment characteristics with data collected by Cornwell and Owens (1997) is presented in Table 19. The Cornwell and Owen data have been converted to model units. It should be noted that direct comparison of these data with the model sediment characteristics is difficult for the following reasons:

Table 17
Bulk Characteristics of Composite Sediment

Substance	Density, g/cu m
Labile particulate organic carbon	46.7
Refractory particulate organic carbon	759
Inert particulate organic carbon	9.90×10^4
Labile particulate organic nitrogen	7.58
Refractory particulate organic nitrogen	168
Inert particulate organic nitrogen	1.41×10^3
Labile particulate organic phosphorus	0.41
Refractory particulate organic phosphorus	10.7
Inert particulate organic phosphorus	146
Ammonium	9.79
Nitrate	0.077
Total inorganic phosphorus	174
Chemical oxygen demand	3.08

Table 18
Release by Complete Elutriation

Substance	Release, kg/day				
	Year 1	Year 2	Year 3	Year 4	Year 5
Ammonium	134	242	162	324	108
Nitrate	2	2	2	2	0
Phosphate	2,396	4,312	2,876	5,750	1,916
COD	42	76	50	102	34

Table 19
Comparison of Model Sediment Characteristics with Cornwell and Owens (1997) Data

Substance	Cornwell and Owens	Model
Interstitial NH4	0-45 g m^{-3}	9.8 g m^{-3}
Solid-phase carbon	10,000 - 20,000 g m^{-3}	99,800 g m^{-3}
Solid-phase nitrogen	1,000 - 3,000 g m^{-3}	1,585 g m^{-3}
Solid inorganic phosphorus	250 - 500 g m^{-3}	174 g m^{-3}
Solid total phosphorus	375 - 750 g m^{-3}	331 g m^{-3}

a. Model concentrations are bulk properties, while the data are interstitial concentrations or solid fractions.

b. Model concentrations are averaged over the top 10 cm, while the data are presented at various depths.

c. Model concentrations are long-term average, while the data were collected during the summer.

d. The model partitions organic particulates into reactive fractions. while the data are not partitioned.

In addition, one should remember that the model concentrations are for sediment to be placed at Site 104, whereas, the Cornwell and Owens data are for sediments that already exist at Site 104.

Results of the No-Elutriation Run

Results are presented in several formats. Each compares a set of base conditions (no placement) with proposed conditions (placement of material). The first set of plots (Figure 84) shows time series of benthic sediment-water interactions (sediment-water fluxes) and of properties in the sediments. One key feature is a slightly enhanced sediment-ammonium release during the dredging season (Julian Days 305 to 445 and corresponding periods in subsequent years). The enhanced release occurs when subsurface sediments from the dredge sites are deposited at the sediment-water interface at Site 104. A second key feature is enhanced sediment-phosphorus release during periods of bottom-water anoxia (Julian Days 180 to 270 and corresponding periods in subsequent years). The enhanced release occurs because the dredged material placed at the site, which is representative of material in the Baltimore Harbor approach channels, contains more inorganic phosphorus than material already at Site 104. This effect can clearly be seen in the panel entitled "Phosphorus Fraction (TPO4)." The bulk phosphate in the sediment is roughly doubled from 100 to 200 g P/m^3. Similar effects occur with releases of silica and COD from the sediment.

The second set of plots (Figure 85) shows time series in the water column immediately overlying Site 104. Within the scale normally used to examine water quality, the only noticeable impact is a slight increase in dissolved inorganic phosphorus caused by the enhanced sediment release. Impacts on water column ammonium and dissolved oxygen are negligibly small.

The third set of plots (Figure 86) consists of vertical profiles in the water column at Site 104. Results are averaged over seasons of roughly 90 days. These seasons are winter (December - February), spring (March - May), summer (June - August), and autumn (September - November). The Julian day given in each panel is the day at the end of the season (see Table 20). These figures confirm the results of the preceding time series. The only noticeable effect is an

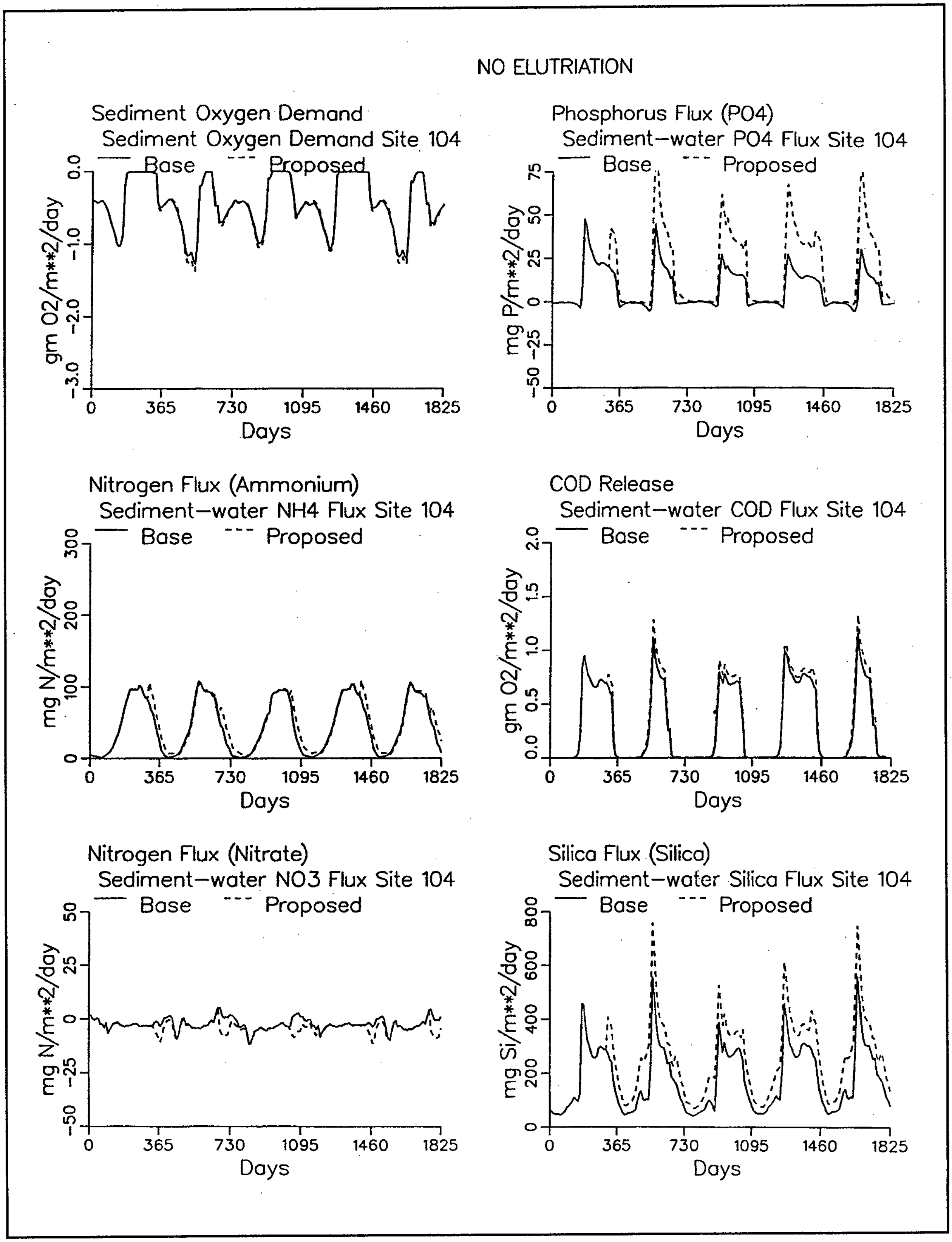


Figure 84. Time series of sediment-water interactions and sediment concentrations with no elutriation (Continued)

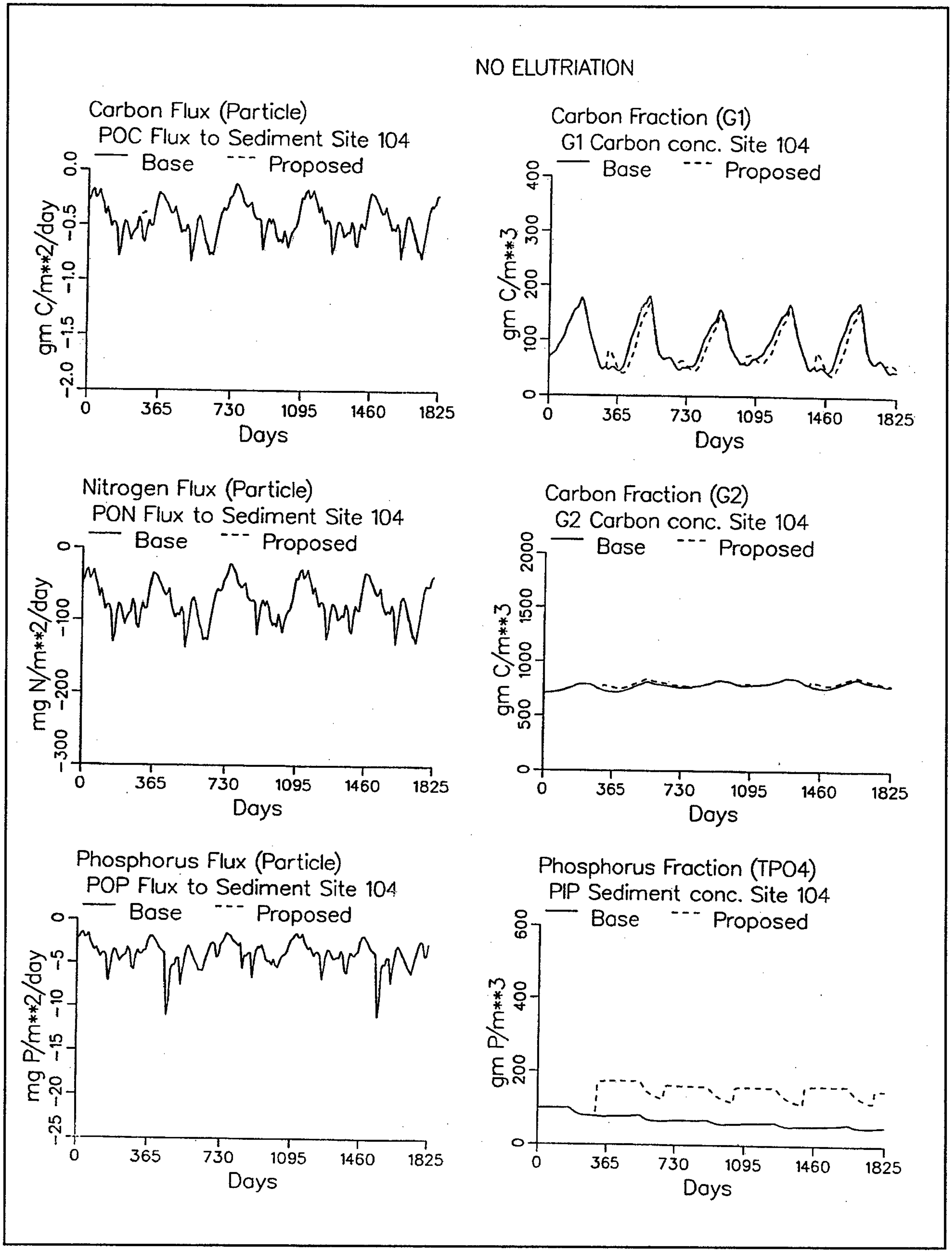


Figure 84. (Concluded)

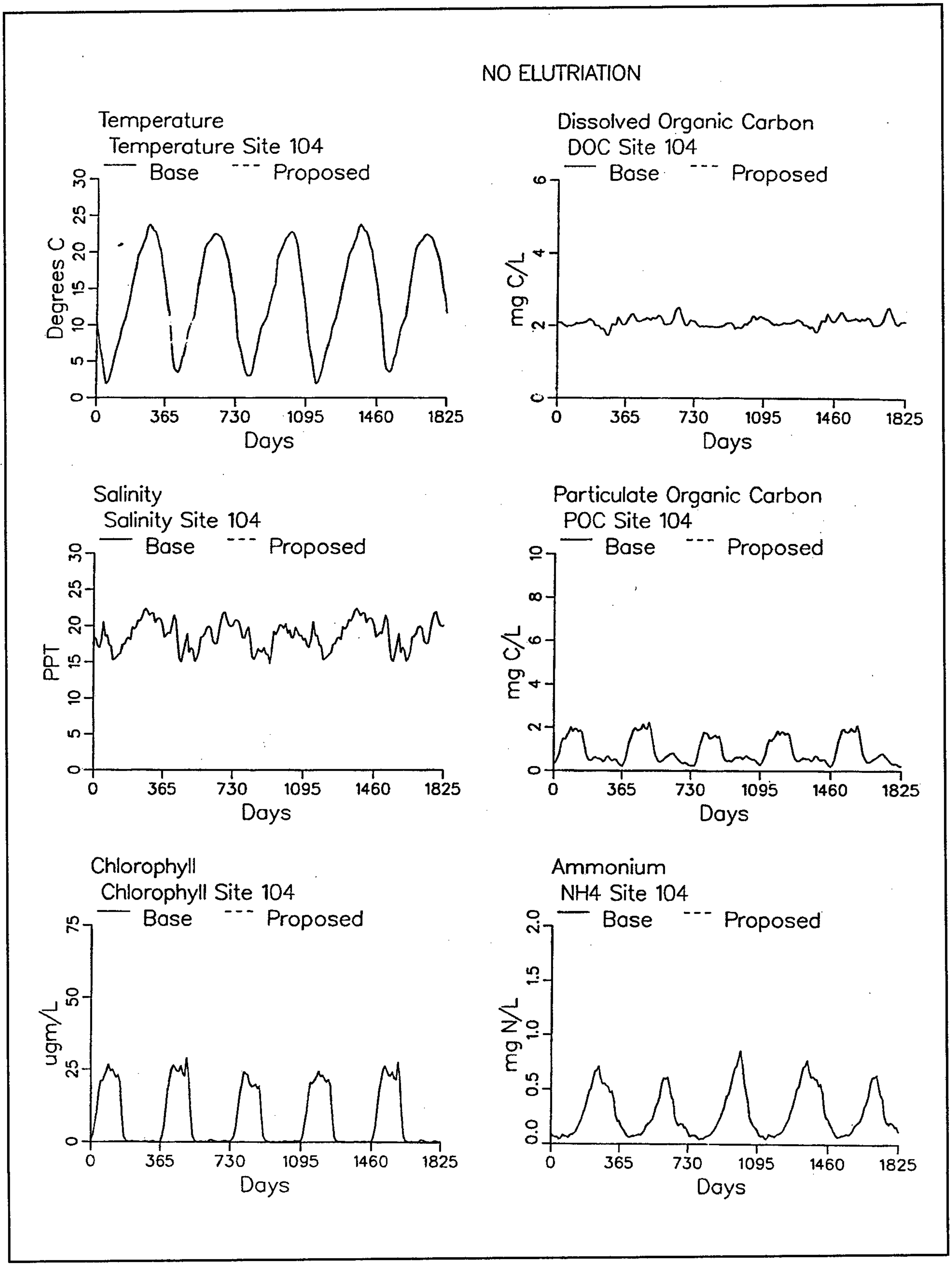
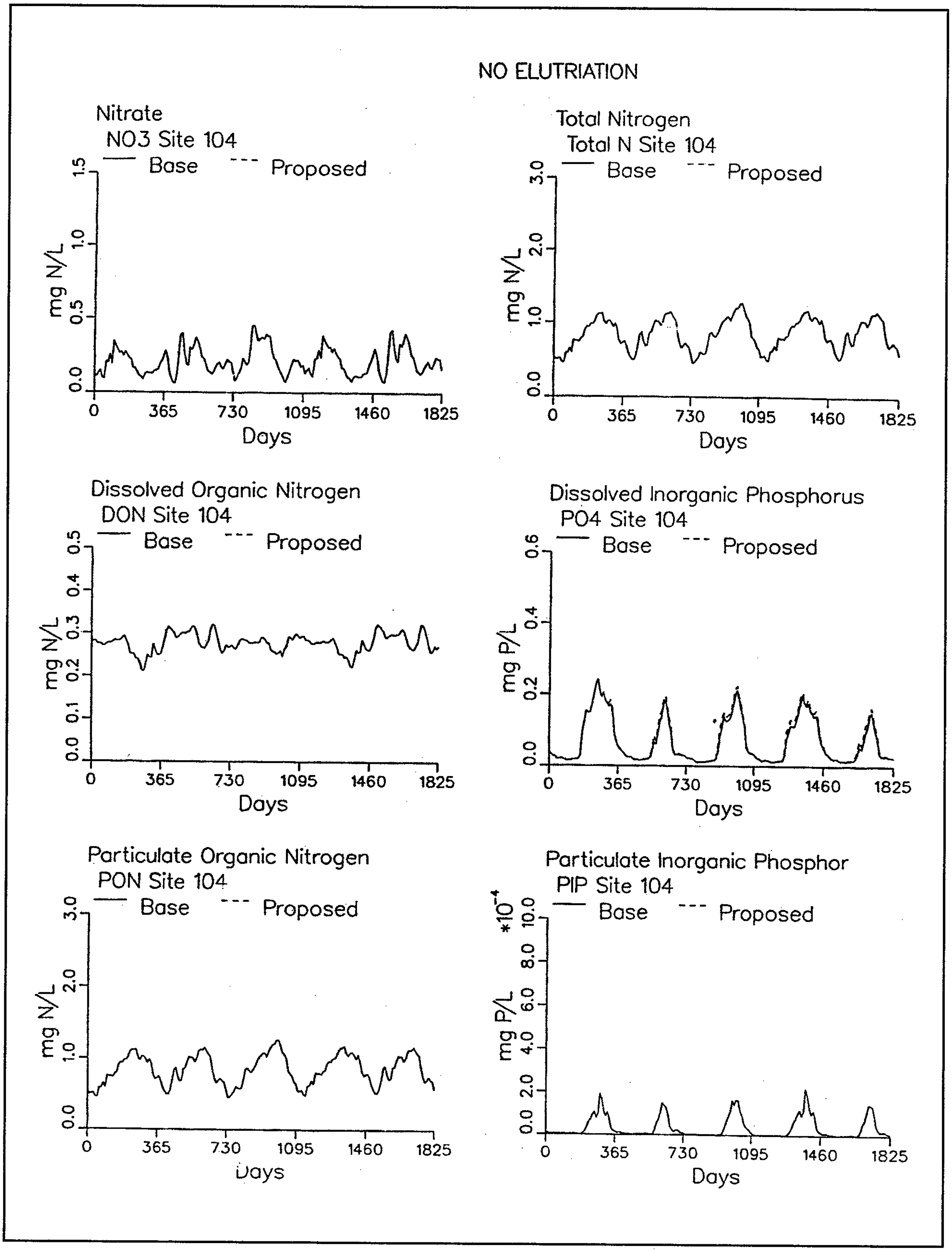


Figure 85. Time series of water quality in bottom waters at Site 104 with no elutriation (Sheet 1 of 3)



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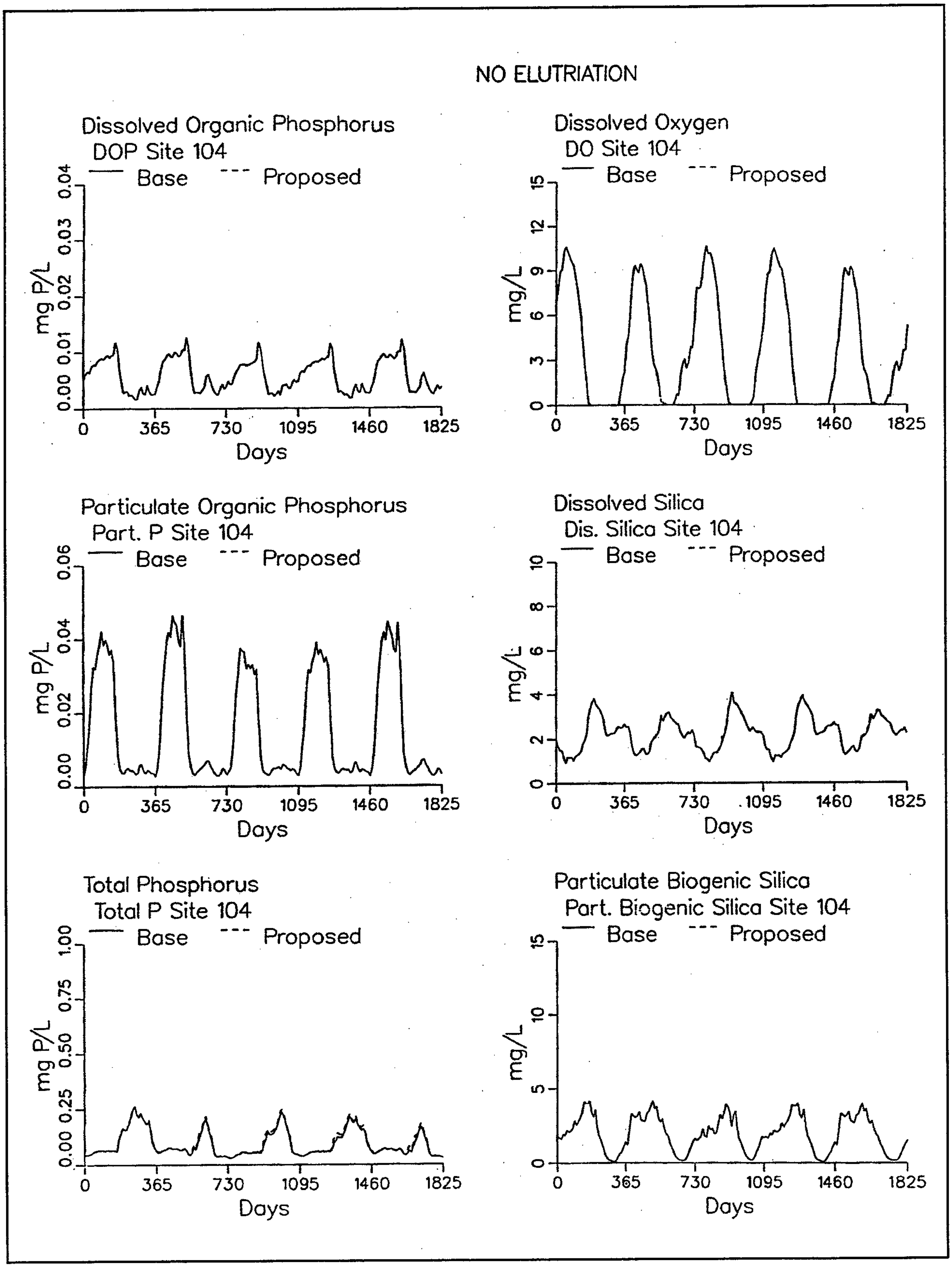


Figure 85. (Sheet 3 of 3)

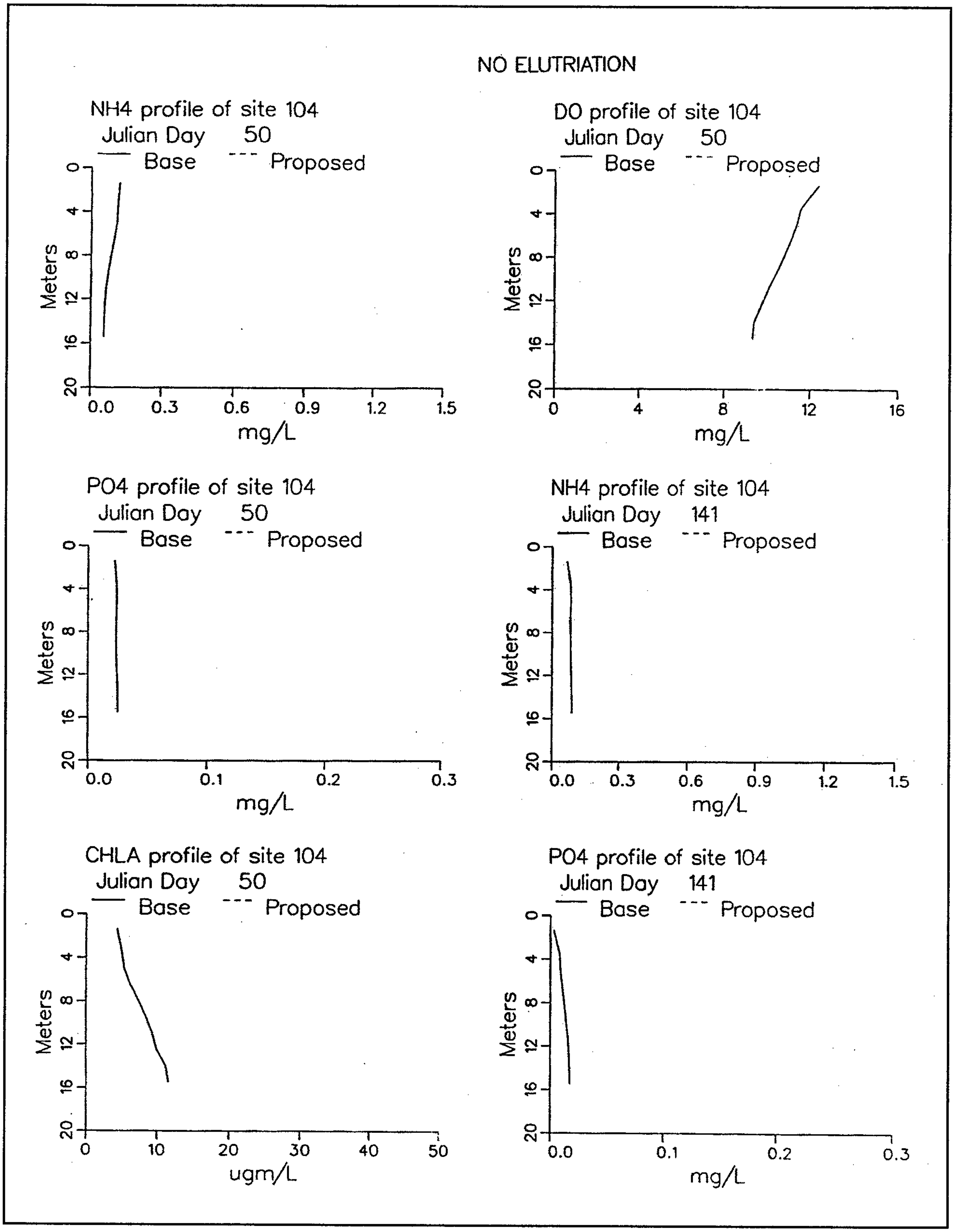
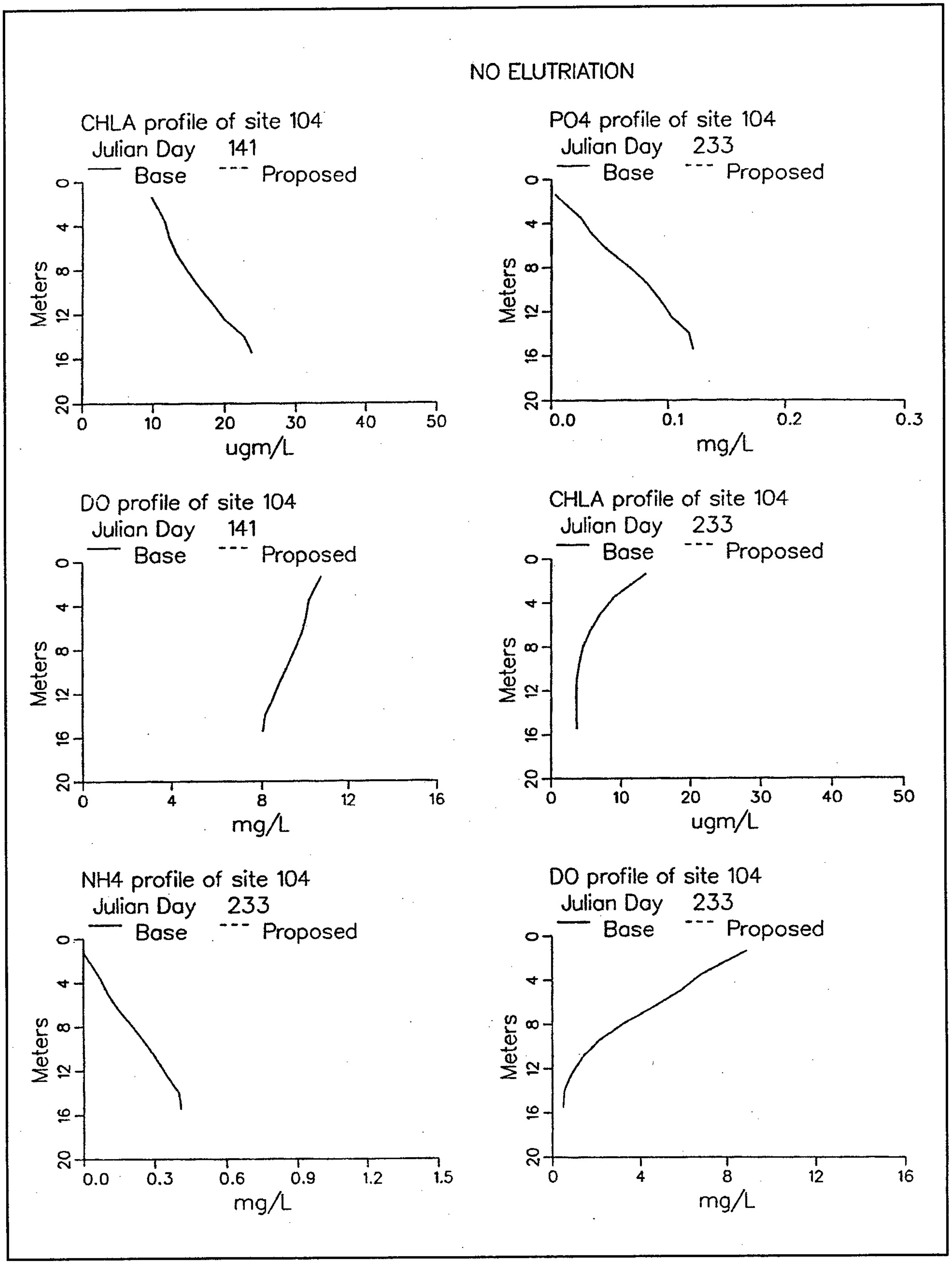


Figure 86. Vertical profiles of key water quality constituents at Site 104 with no elutriation (Sheet 1 of 14)



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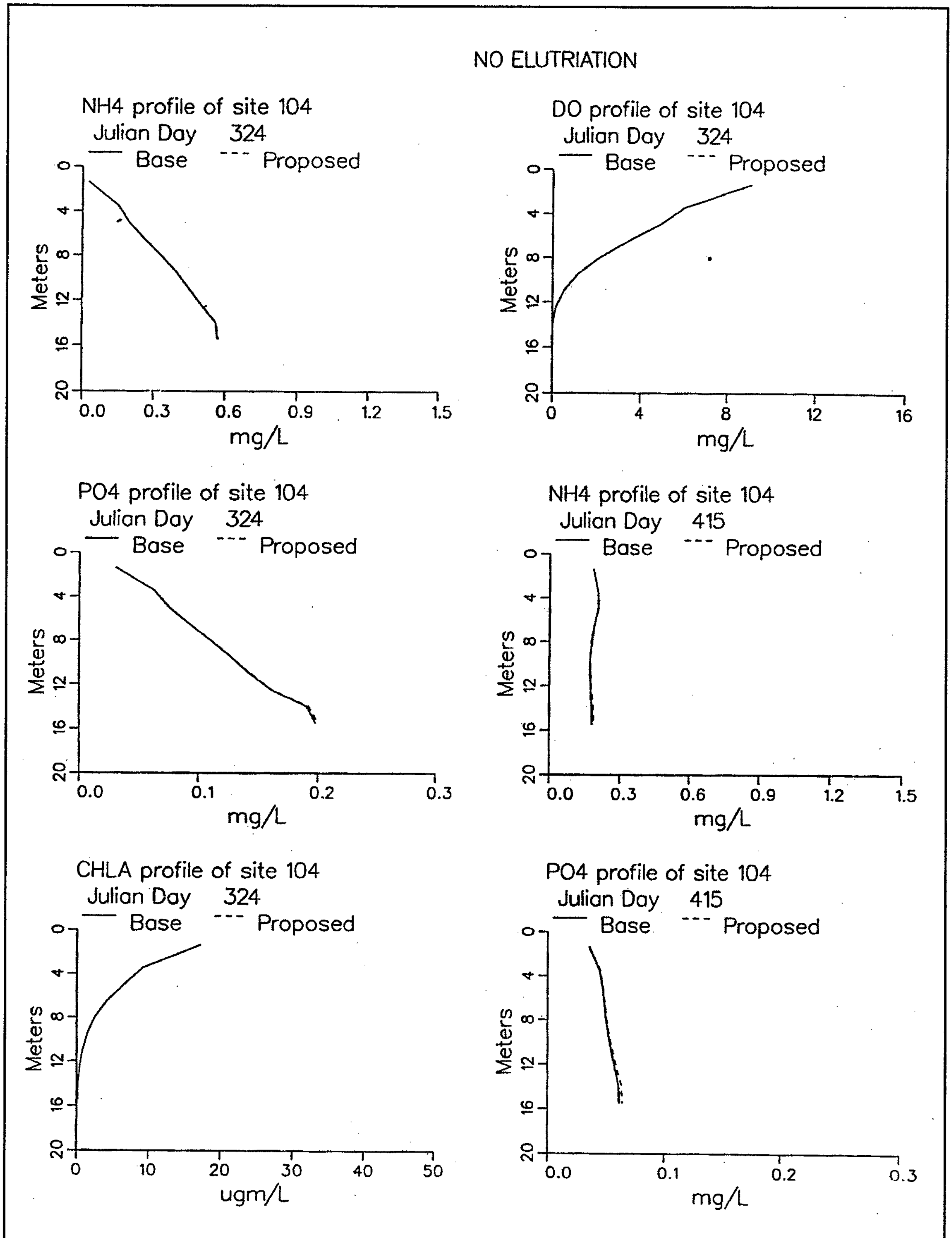

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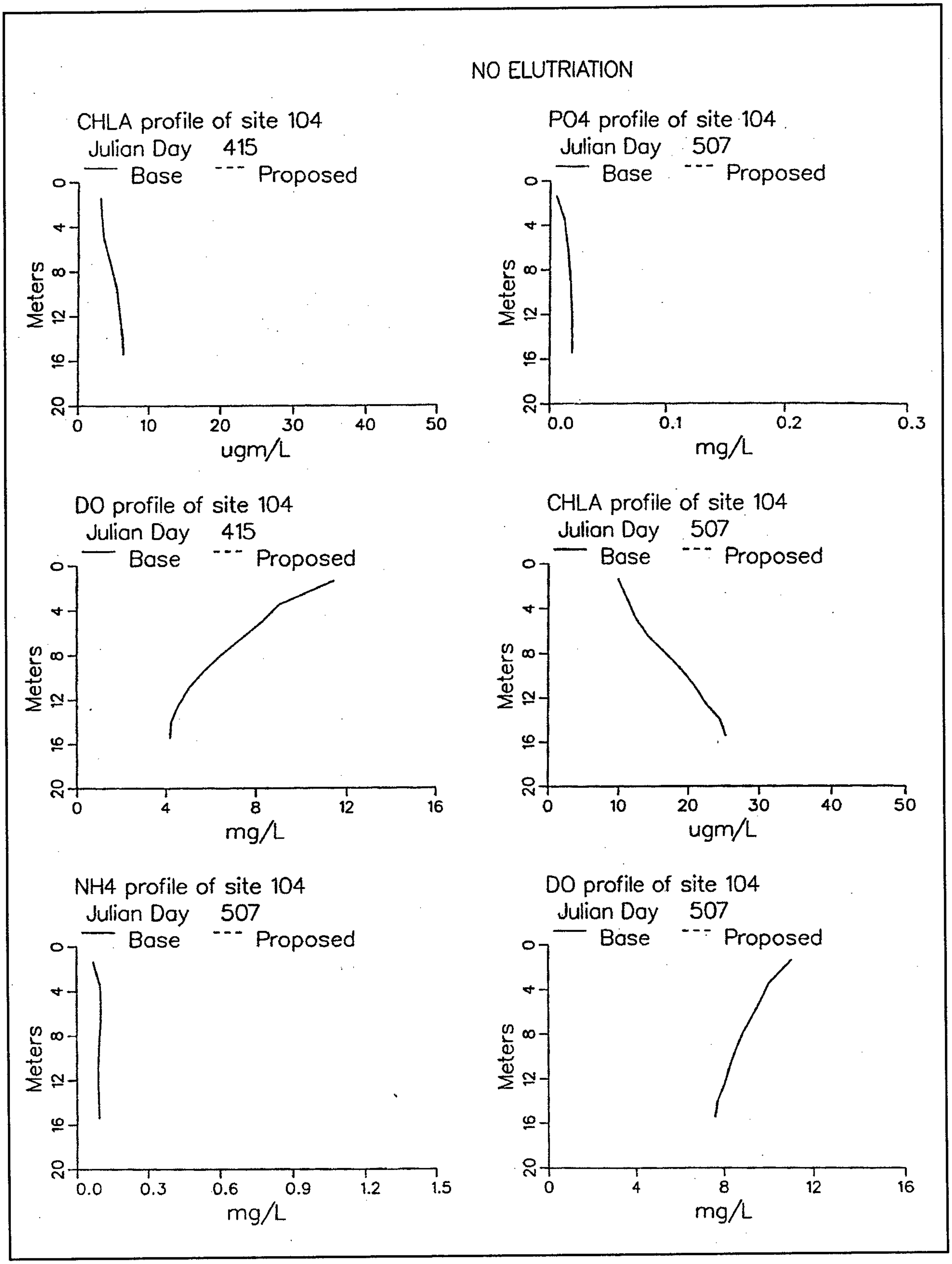

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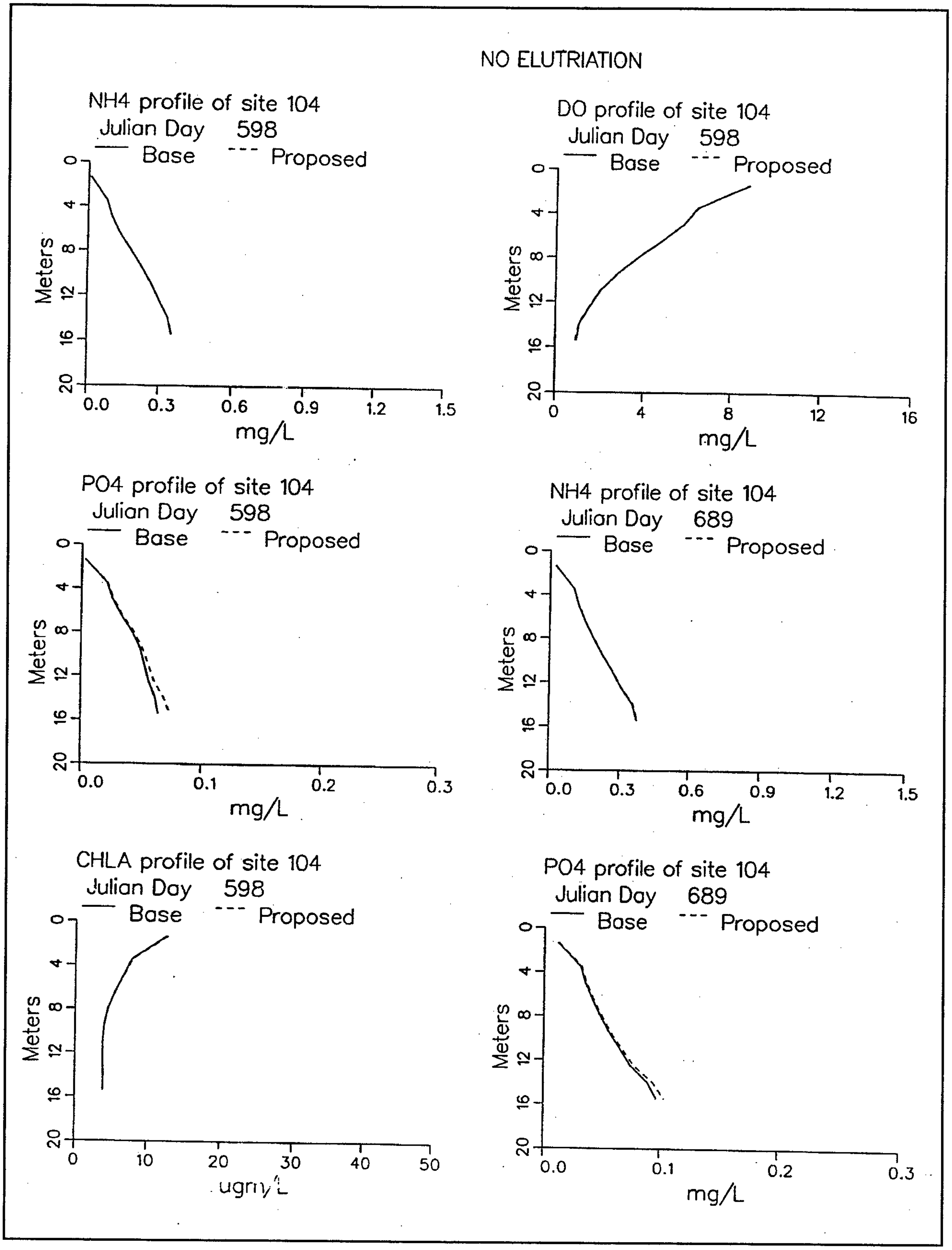

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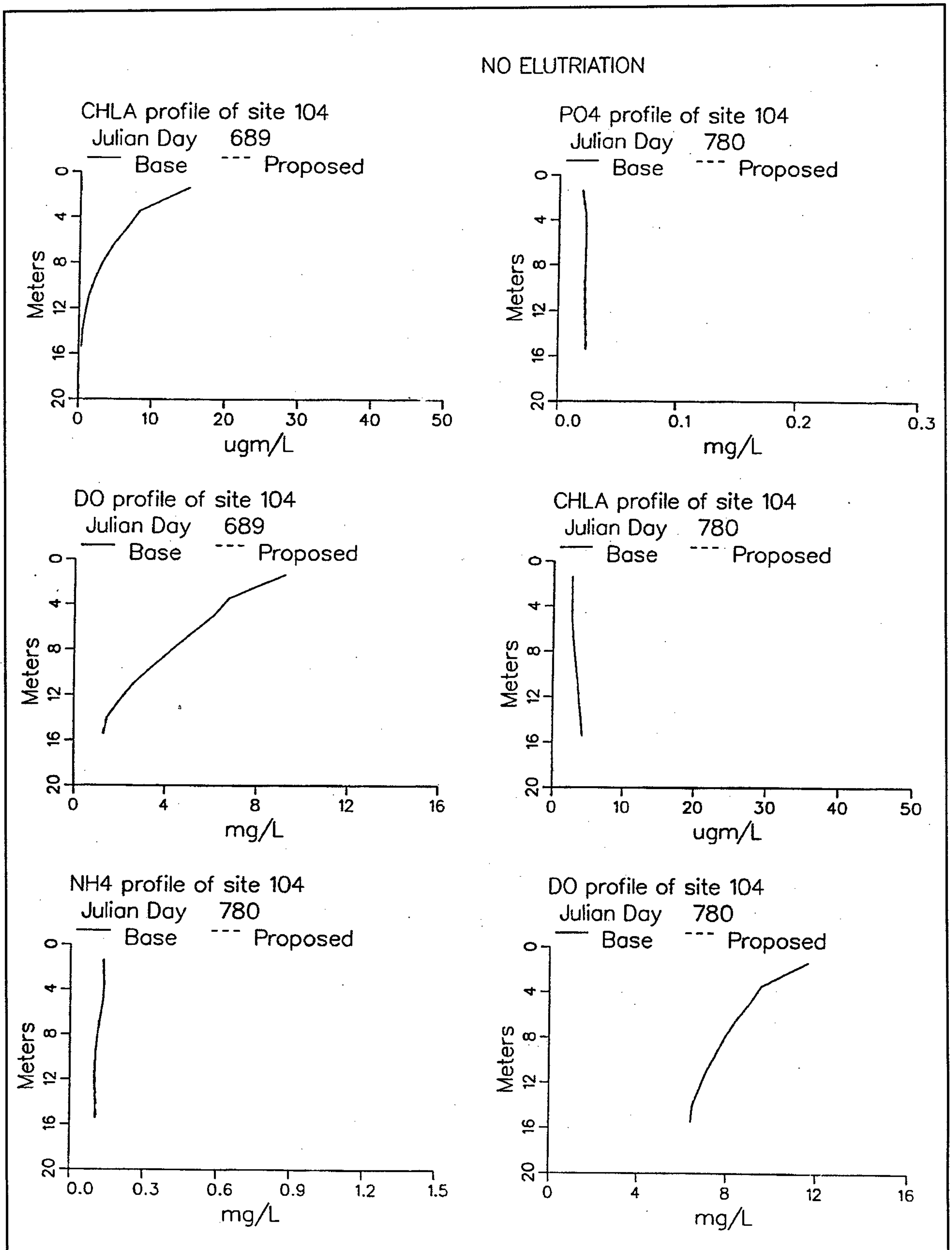

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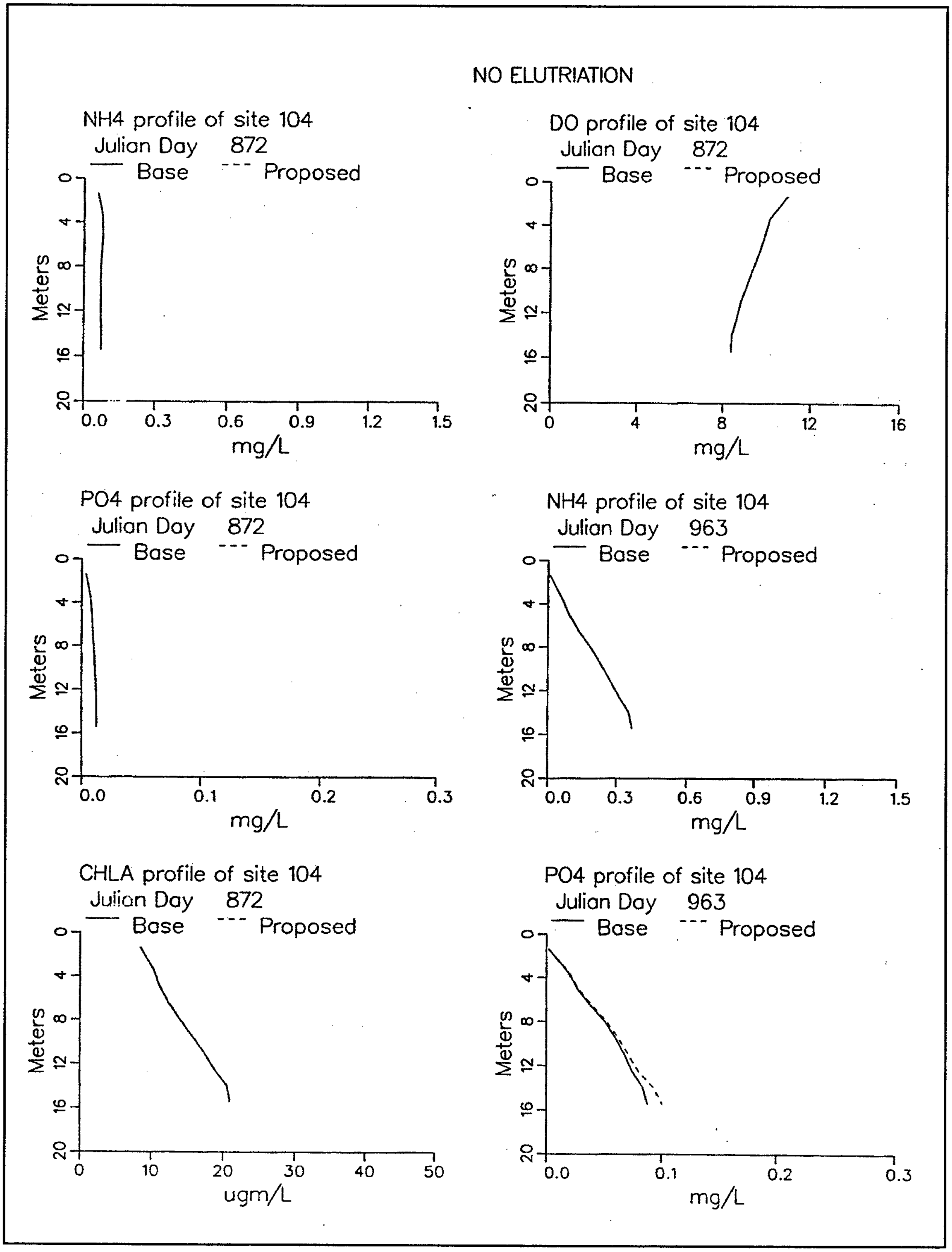

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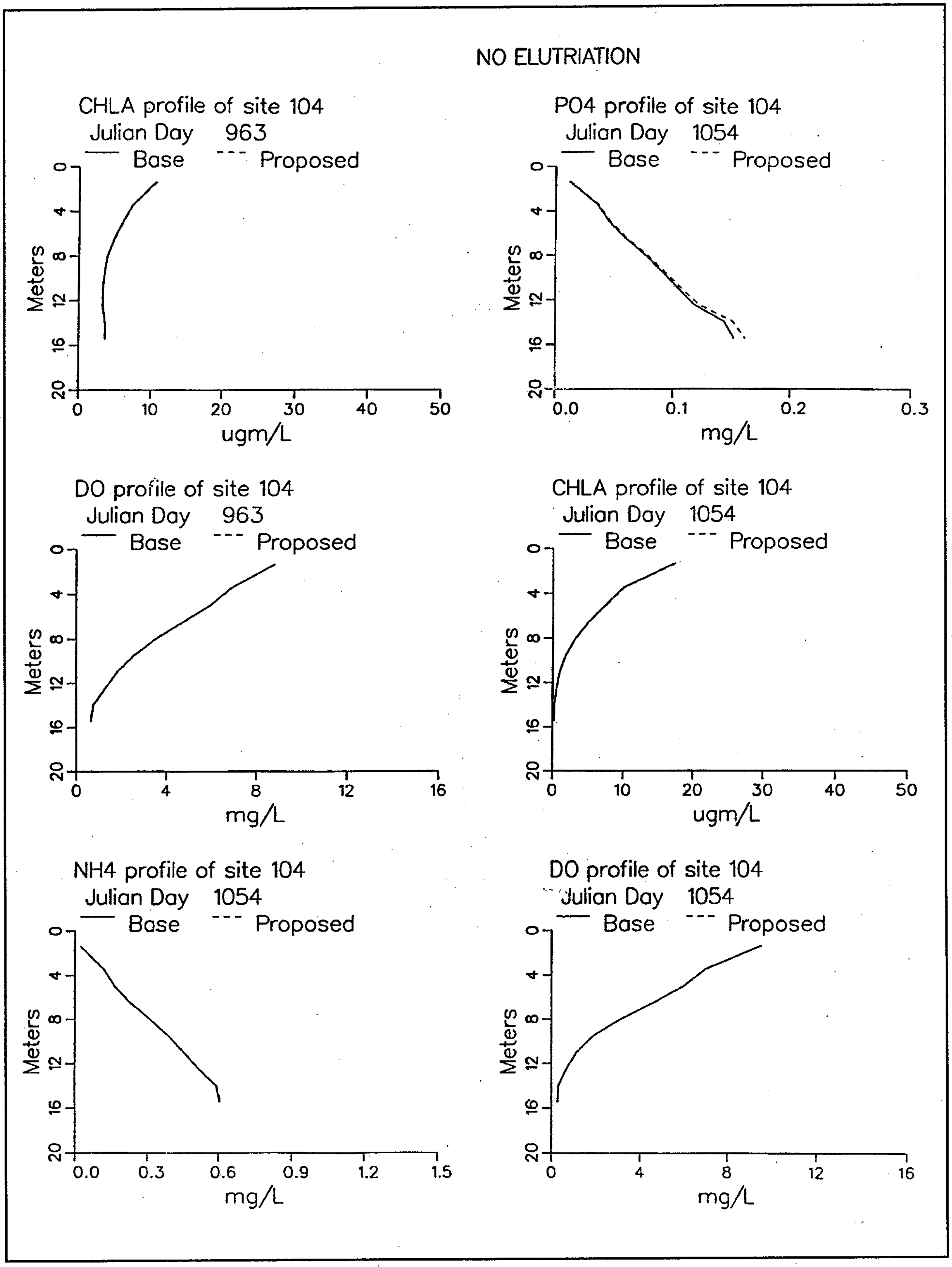

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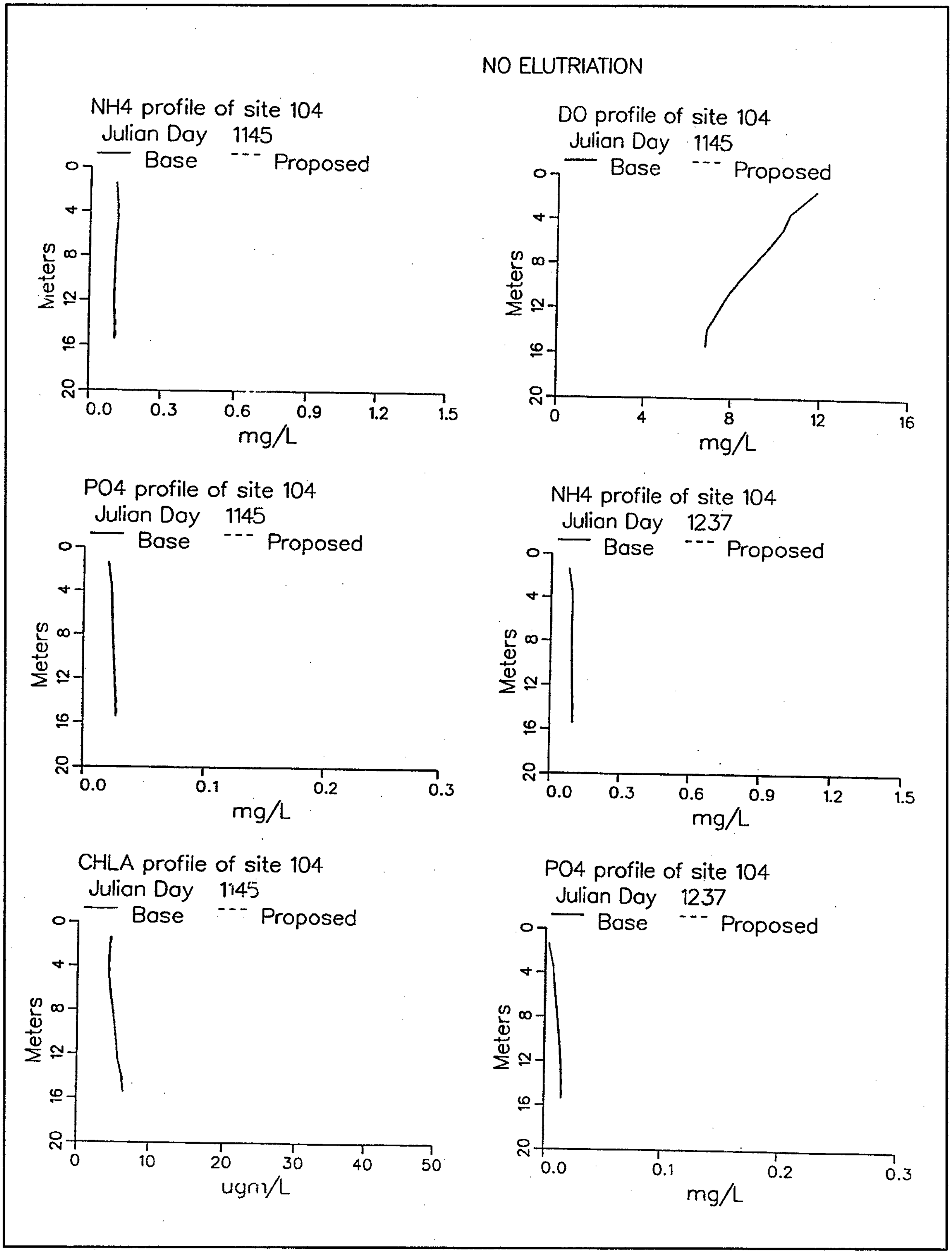

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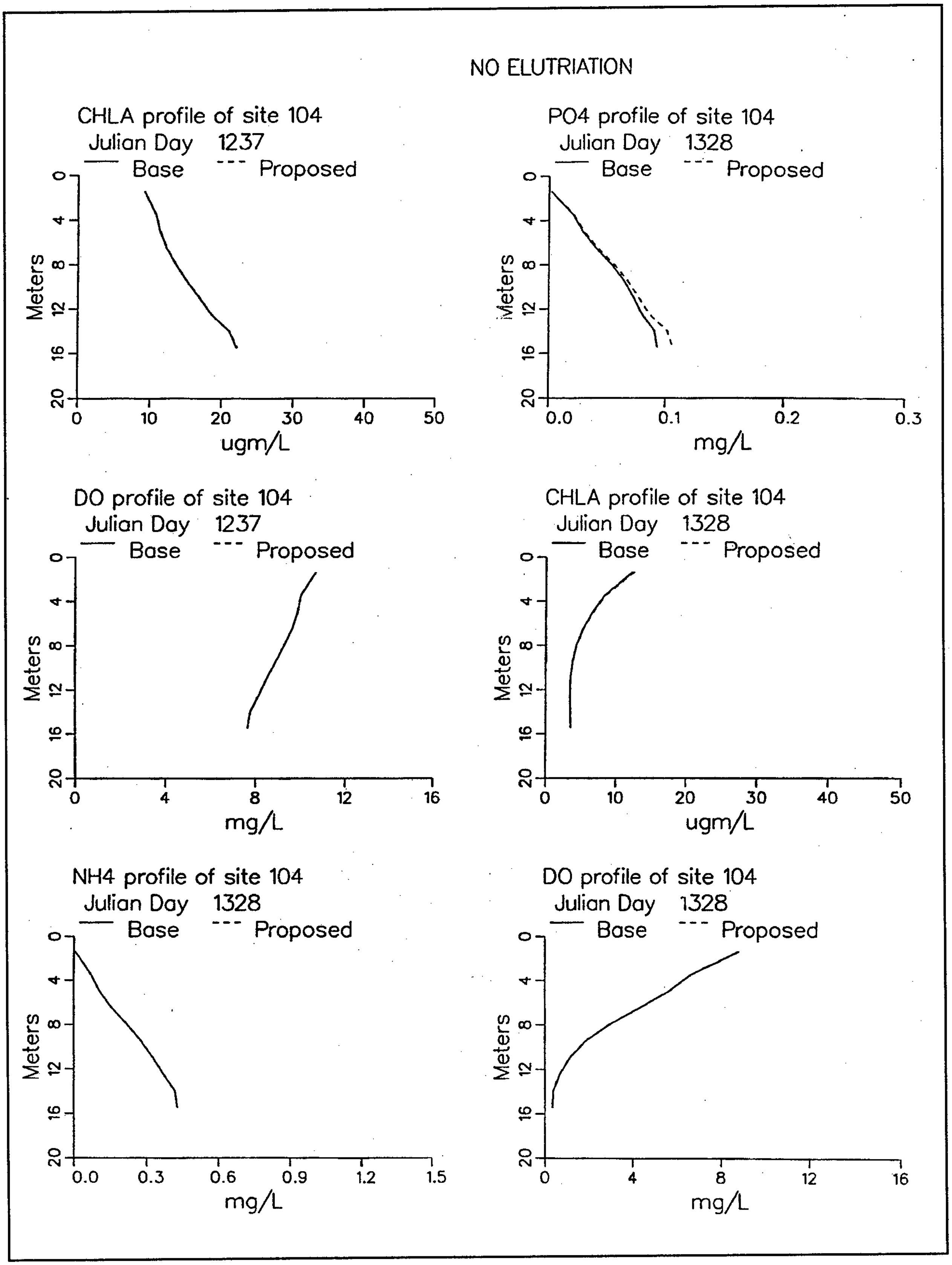

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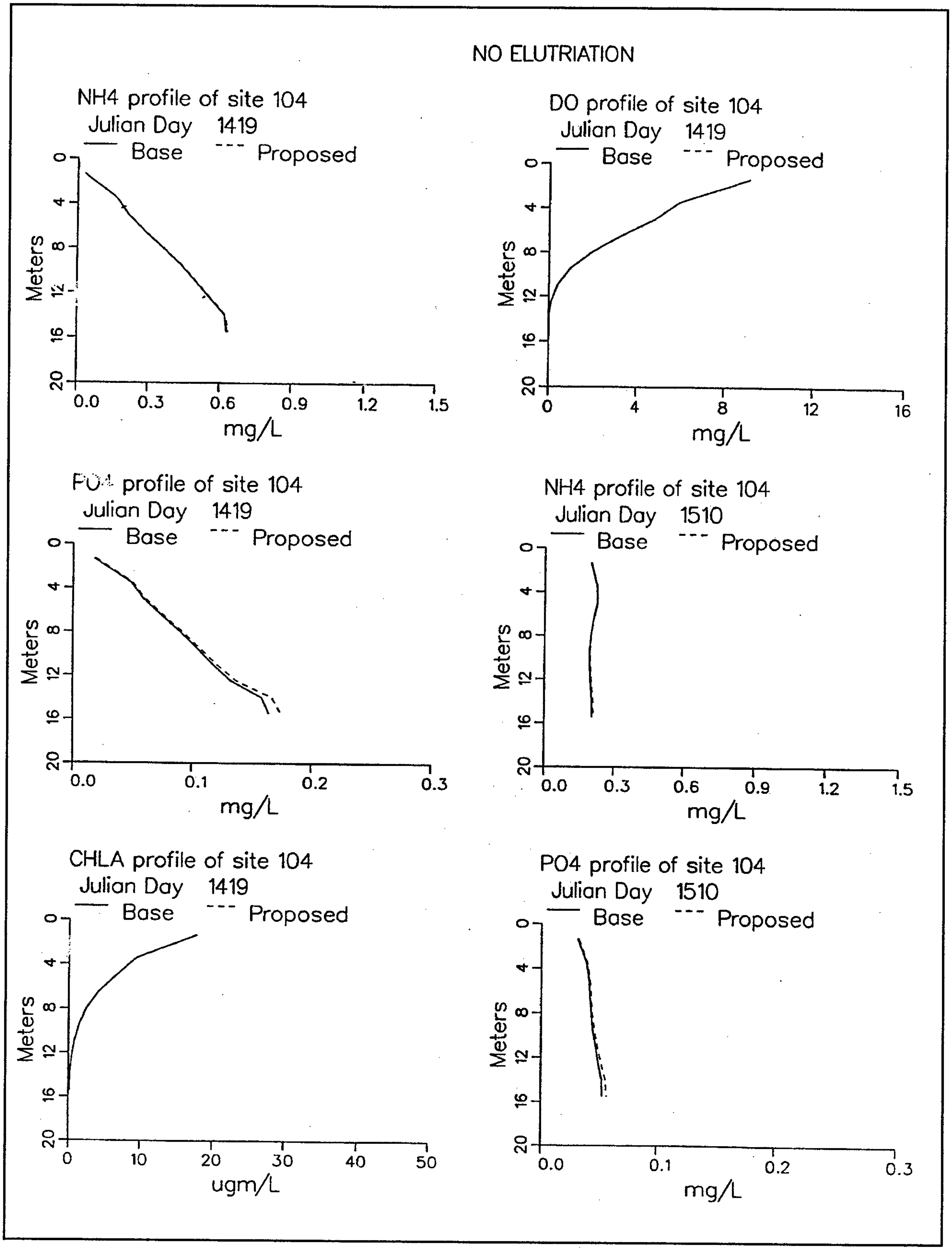

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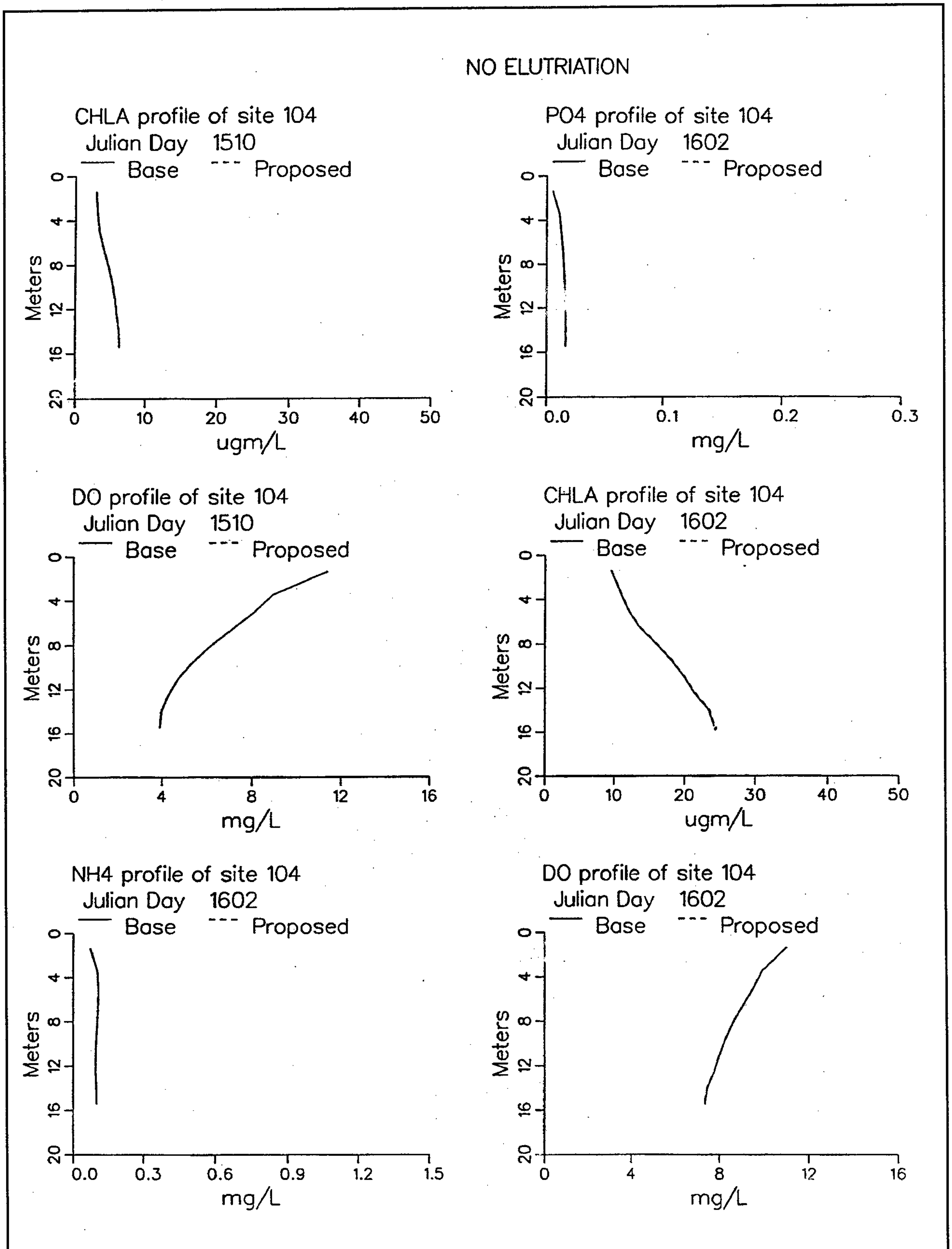

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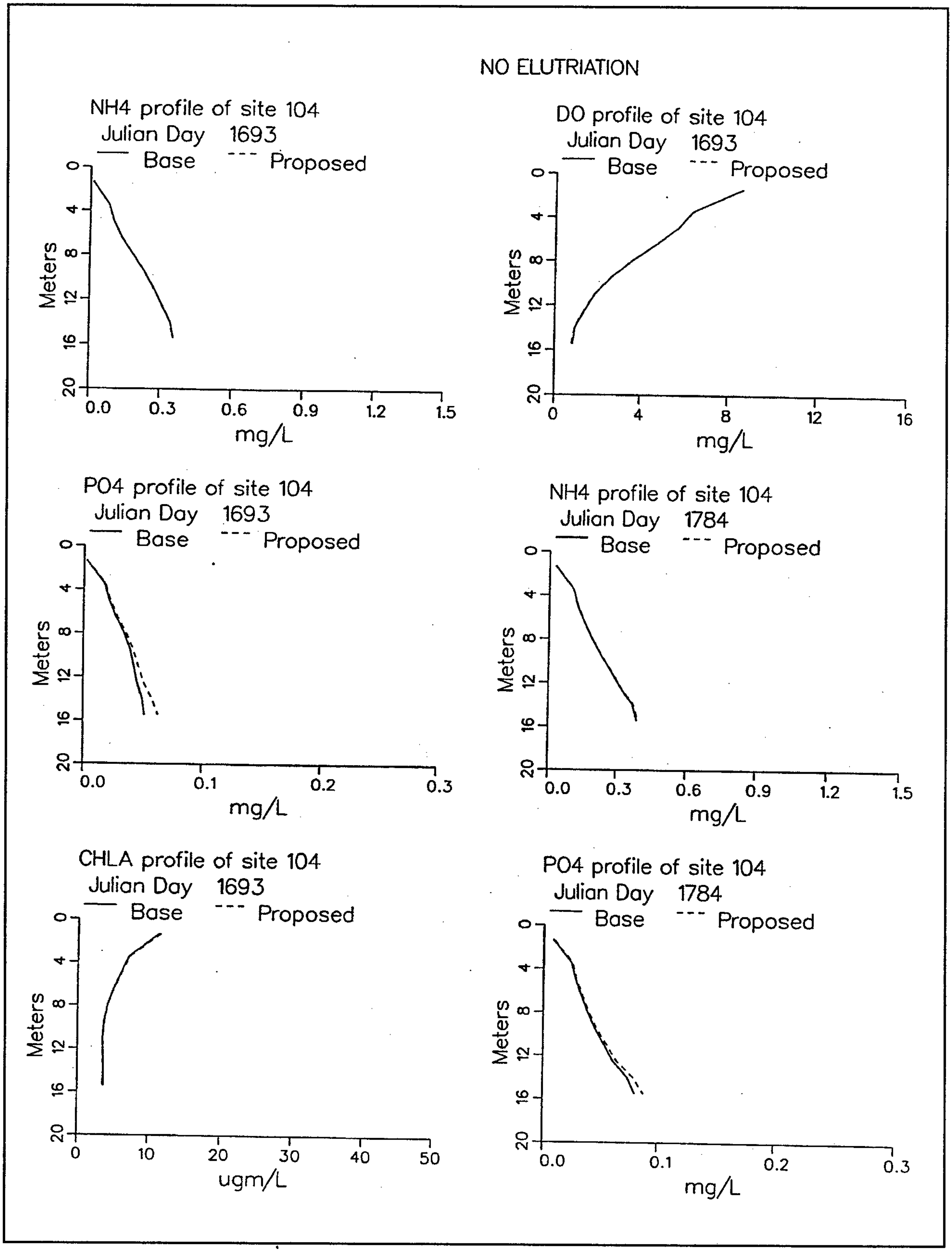


Figure 86. (Sheet 13 of 14)

NO ELUTRIATION

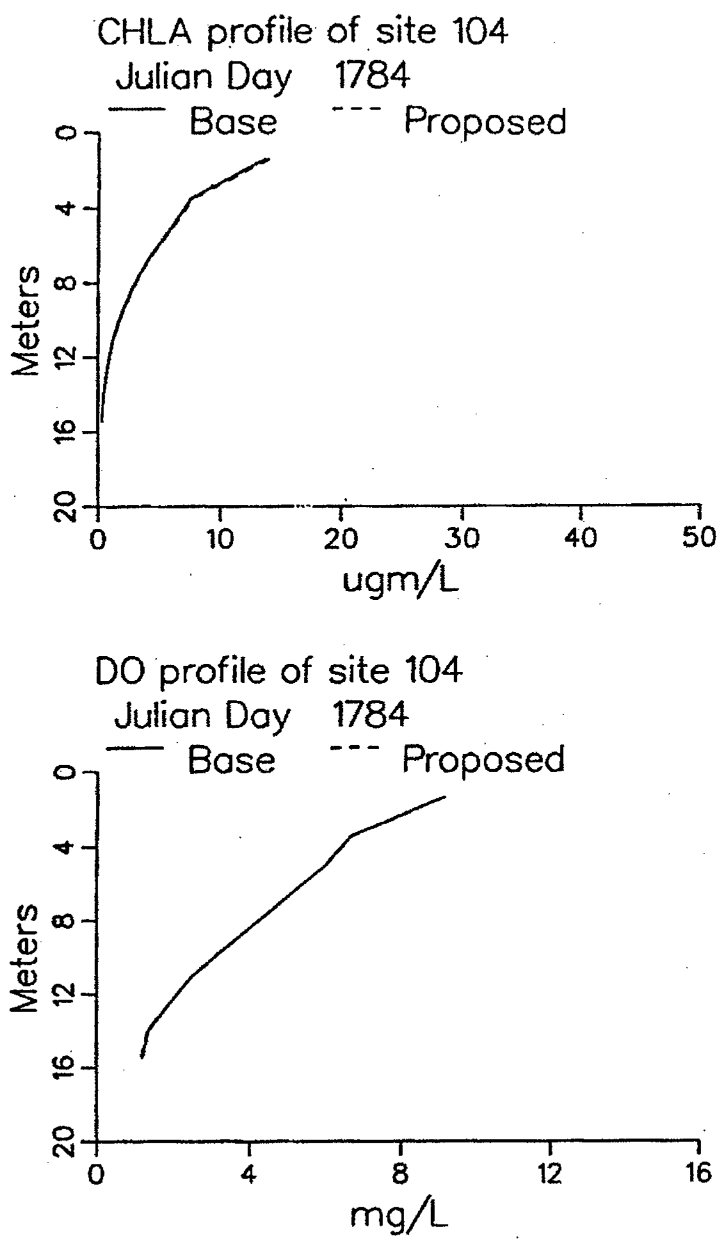


Figure 86. (Sheet 14 of 14)

Table 20
Days for Seasonal Averages

Placement Year	Winter	Spring	Summer	Fall
Year 1	1 - 50	51 - 141	142 - 233	234 - 324
Year 2	325 - 415	416 - 507	508 - 598	599 - 689
Year 3	690 - 780	781 - 872	873 - 963	964 - 1054
Year 4	1055 - 1145	1146 - 1237	1238 - 1328	1329 - 1419
Year 5	1420 - 1510	1511 - 1602	1603 - 1693	1694 - 1784

increase of dissolved inorganic phosphorus, with the increase being greatest during the summer seasons. These figures illustrate further, however, that the impact is restricted to bottom waters immediately over the sediments. Vertical stratification tends to trap the additional phosphorus in bottom waters below the photic zone, so little or no stimulation of algae in surface waters occurs.

Results of the Complete-Elutriation Run

Results of the complete-elutriation run are presented in a format corresponding to the no-elutriation run. Examination of the sediment water fluxes (Figure 87) indicates no significant change from the base conditions. The most interesting contrast is in sediment-phosphorus release between the runs with no elutriation and complete elutriation. The no-elutriation run indicates a buildup of sediment phosphate (TPO4) and enhanced release to the water column. The complete elutriation run indicates small changes in sediment phosphate and no enhanced release. No buildup occurs because the sediment phosphate is released to the water column and eventually dispersed.

Since the phosphate is released to the water column, elevated concentrations are noted at the bottom during placement seasons but not at other times (Figure 88). The phosphorus has a slight stimulatory affect on the spring algal bloom (Figure 89) but no apparent affect on summer chlorophyll levels. The different effect on spring and summer algal concentrations is due to the timing of the placement. The phosphorus released by elutriation is dispersed before the summer algal population appears. The releases by elutriation of ammonium, nitrate, and COD are minor, so no influence on water column nitrogen or oxygen is apparent. Long-term effects of the stimulated spring algal bloom also appear negligible.

In addition to analyzing model results at Site 104, also of interest is viewing results away from the site, e.g., at the mouth of the Chester River. Figure 90 presents time series plots of water quality constituents near the surface and near the bottom at the mouth of the Chester River for the case of complete elutriation. No impact was computed for the case of no elutriation. Because of the net transport near the bottom being directed to the north, one can see a slight impact

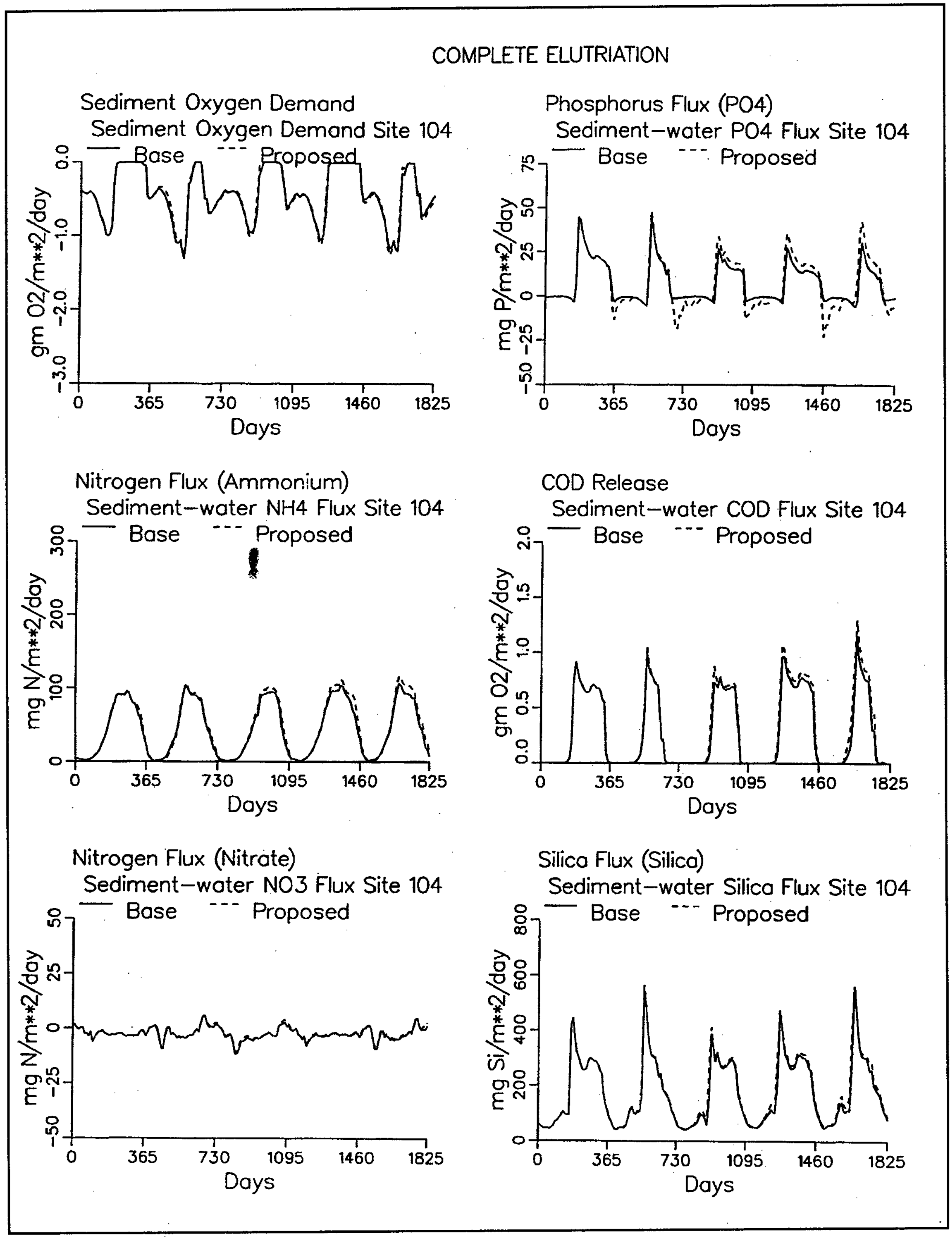
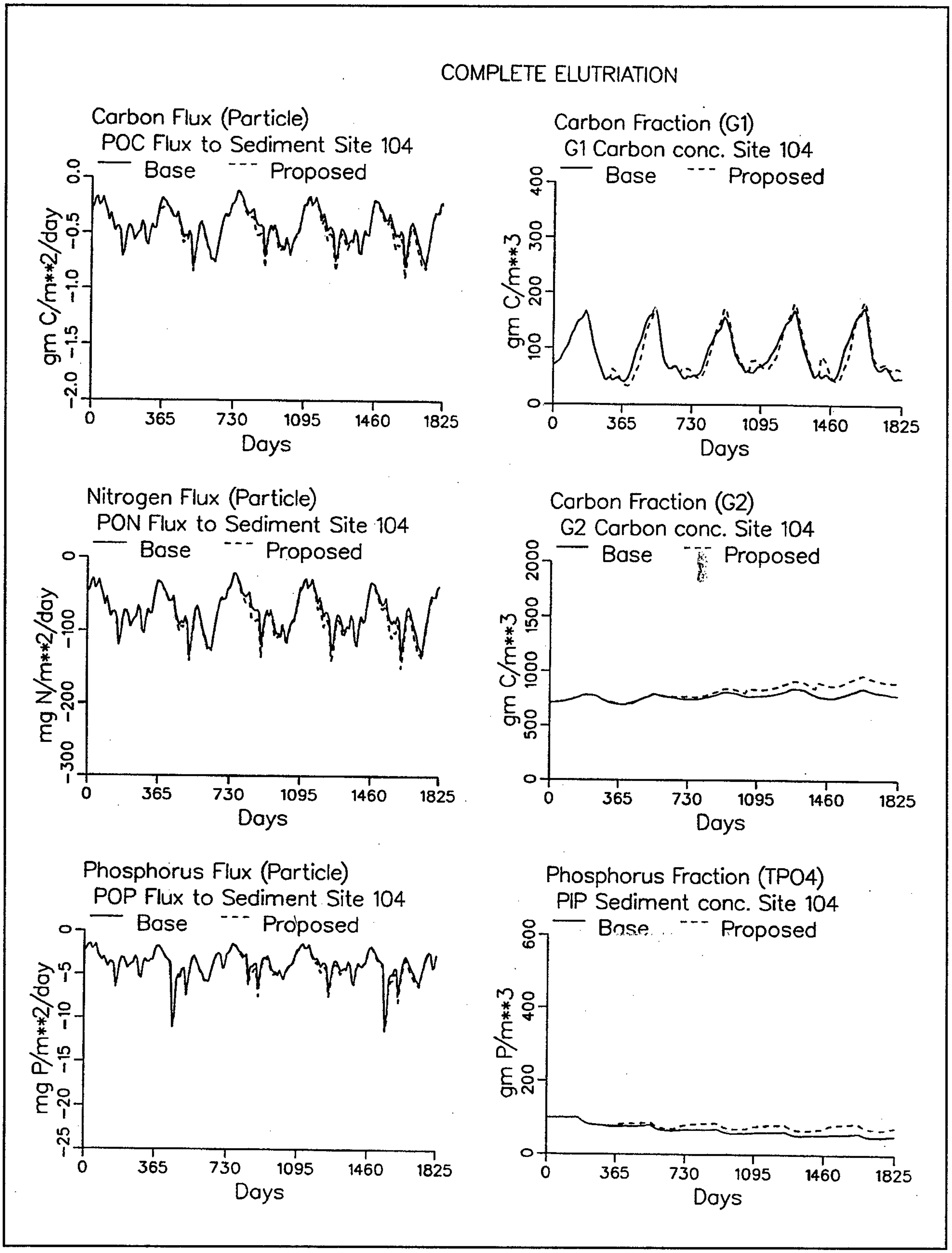


Figure 87. Time series of sediment-water interactions and sediment concentrations with complete elutriation (Continued)



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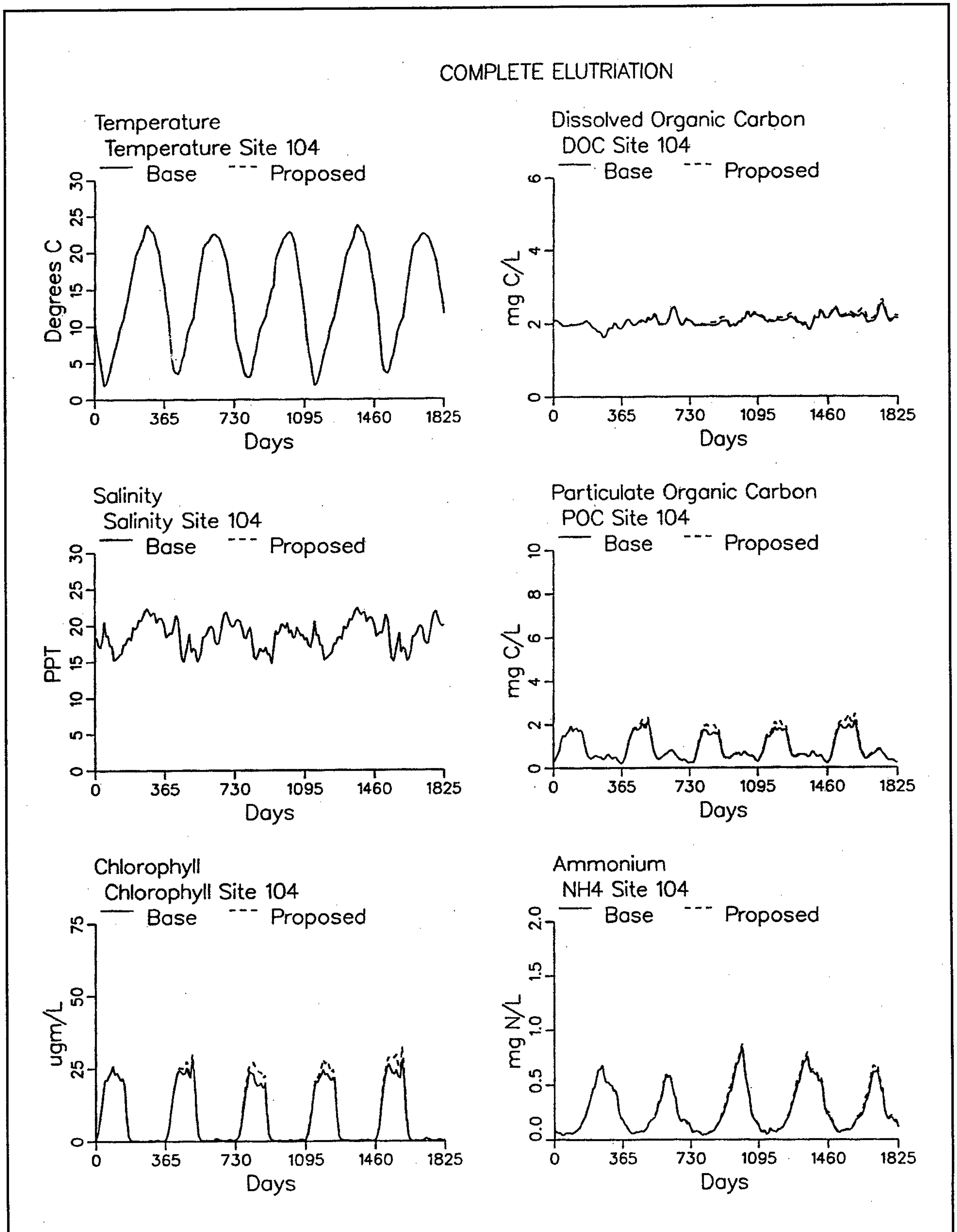


Figure 88. Time series of water quality in bottom waters at Site 104 with complete elutriation (Sheet 1 of 3)

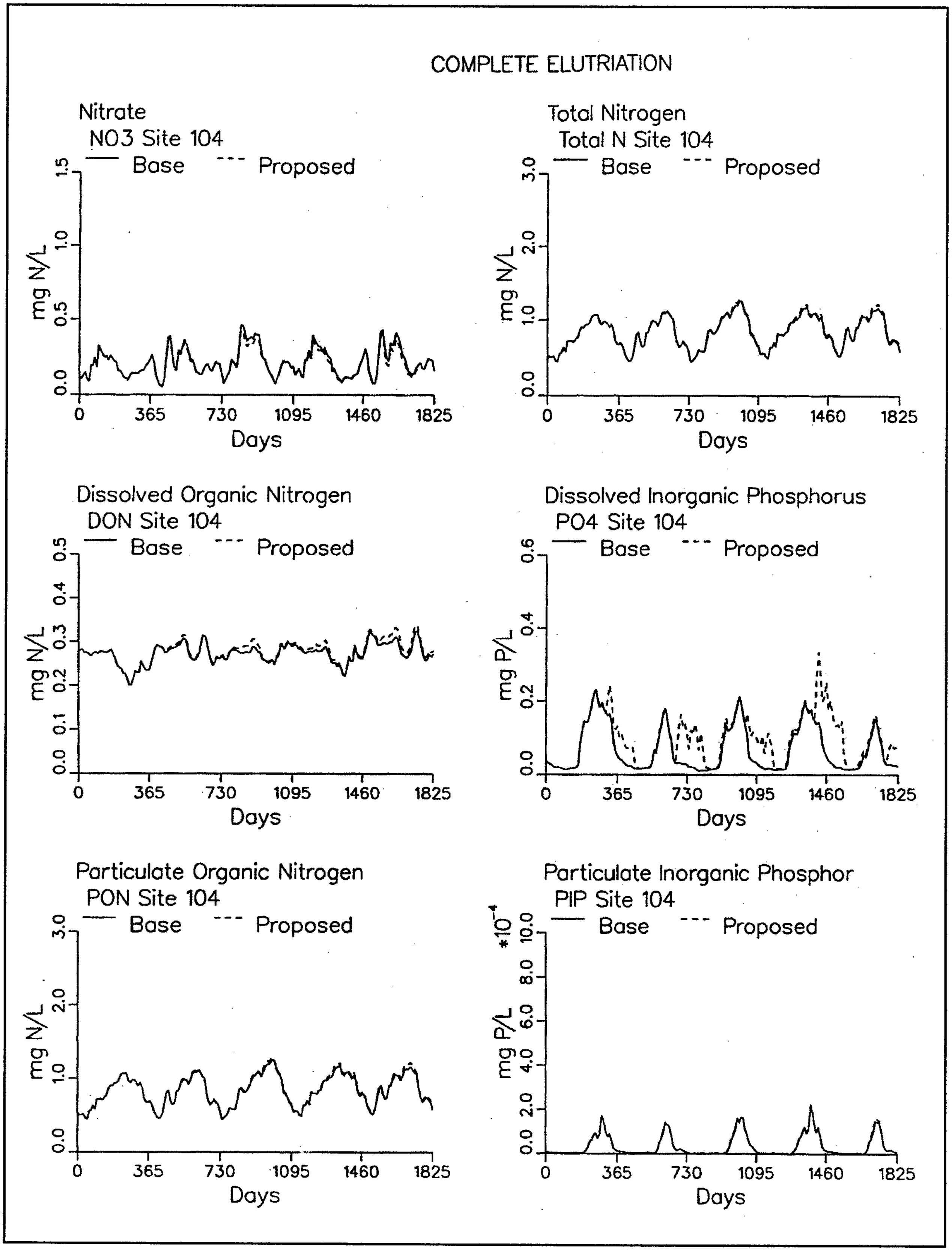


Figure 88. (Sheet 2 of 3)

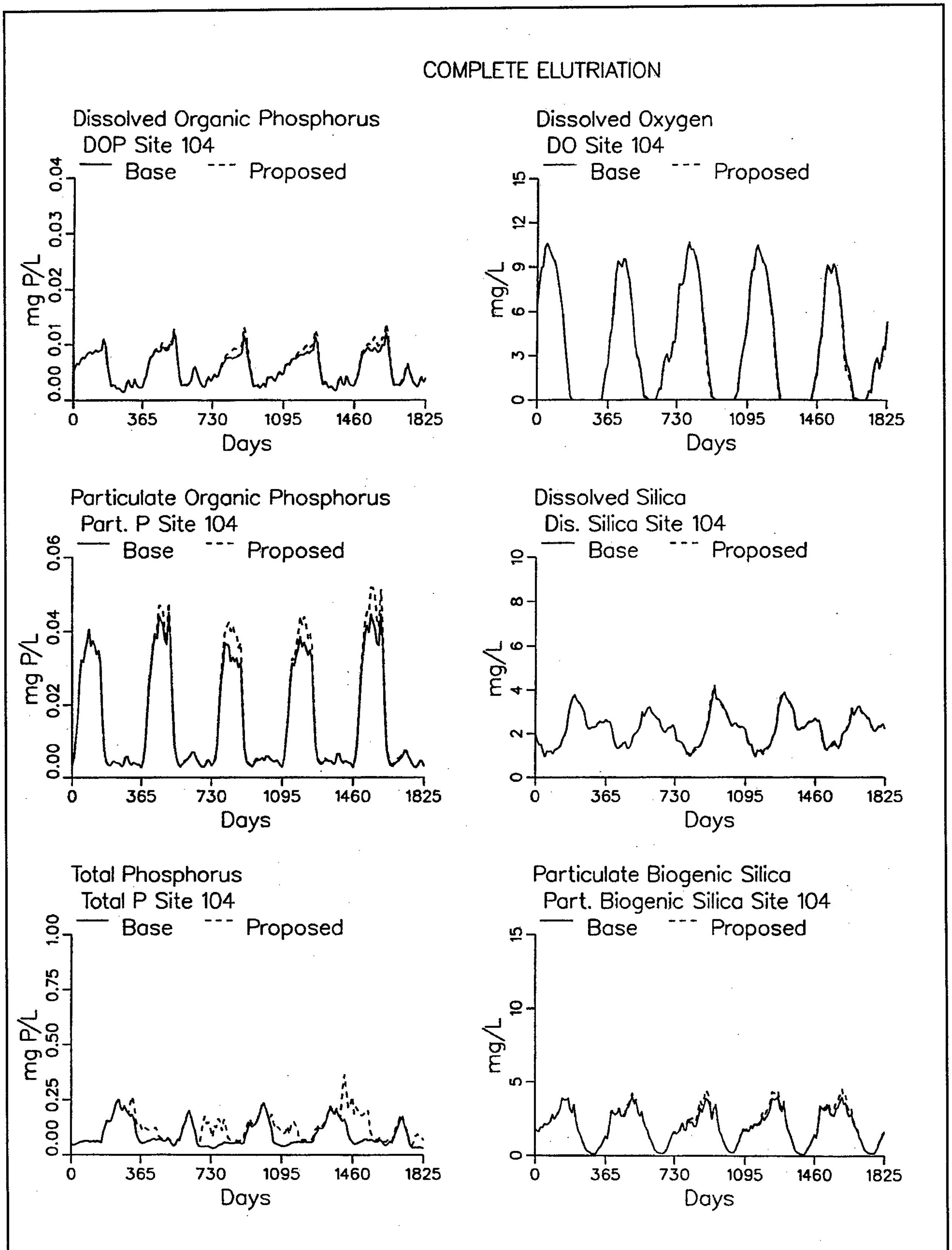


Figure 88. (Sheet 3 of 3)

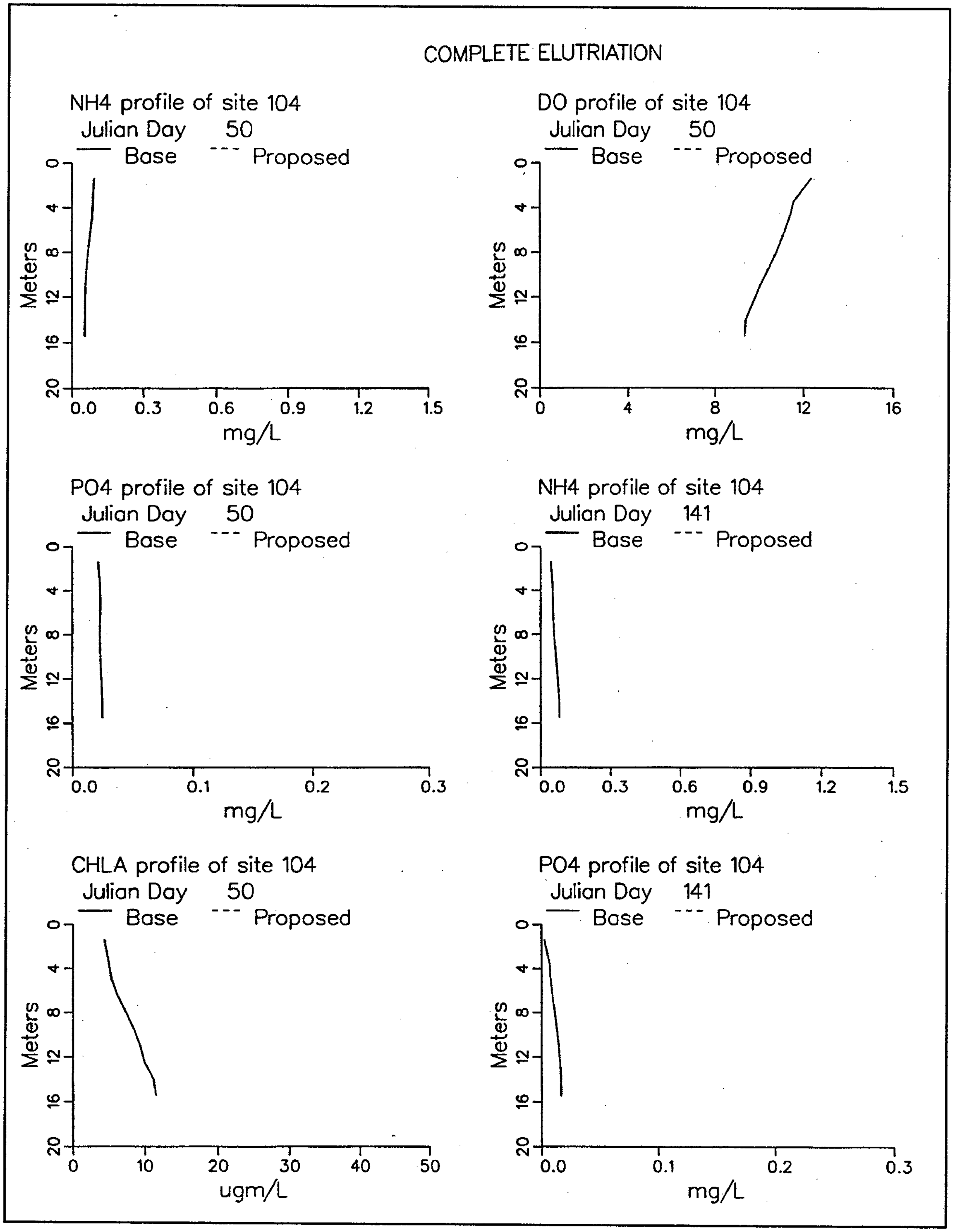
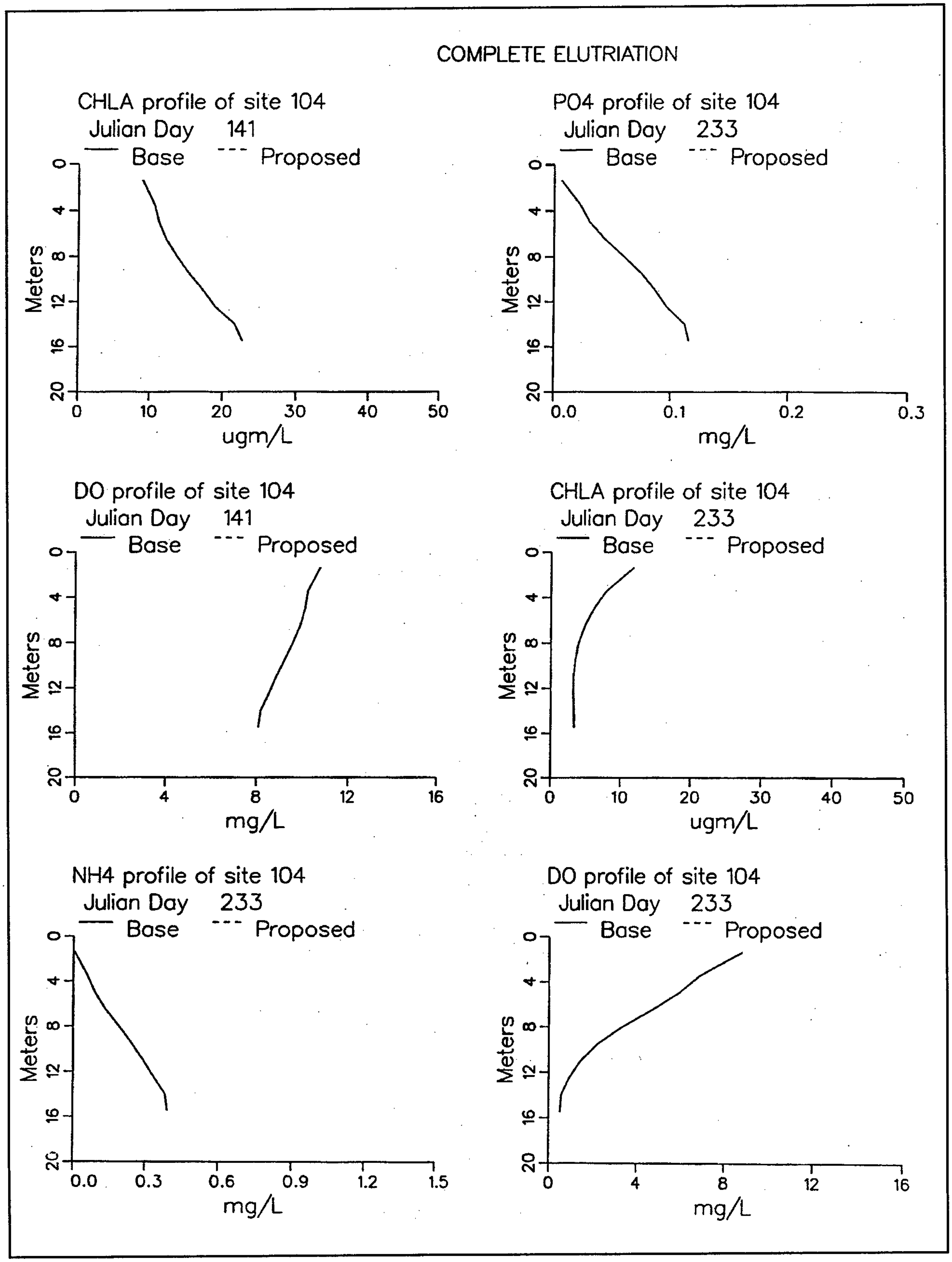


Figure 89. Vertical profiles of key water quality constituents at Site 104 with complete elutriation (Sheet 1 of 14)



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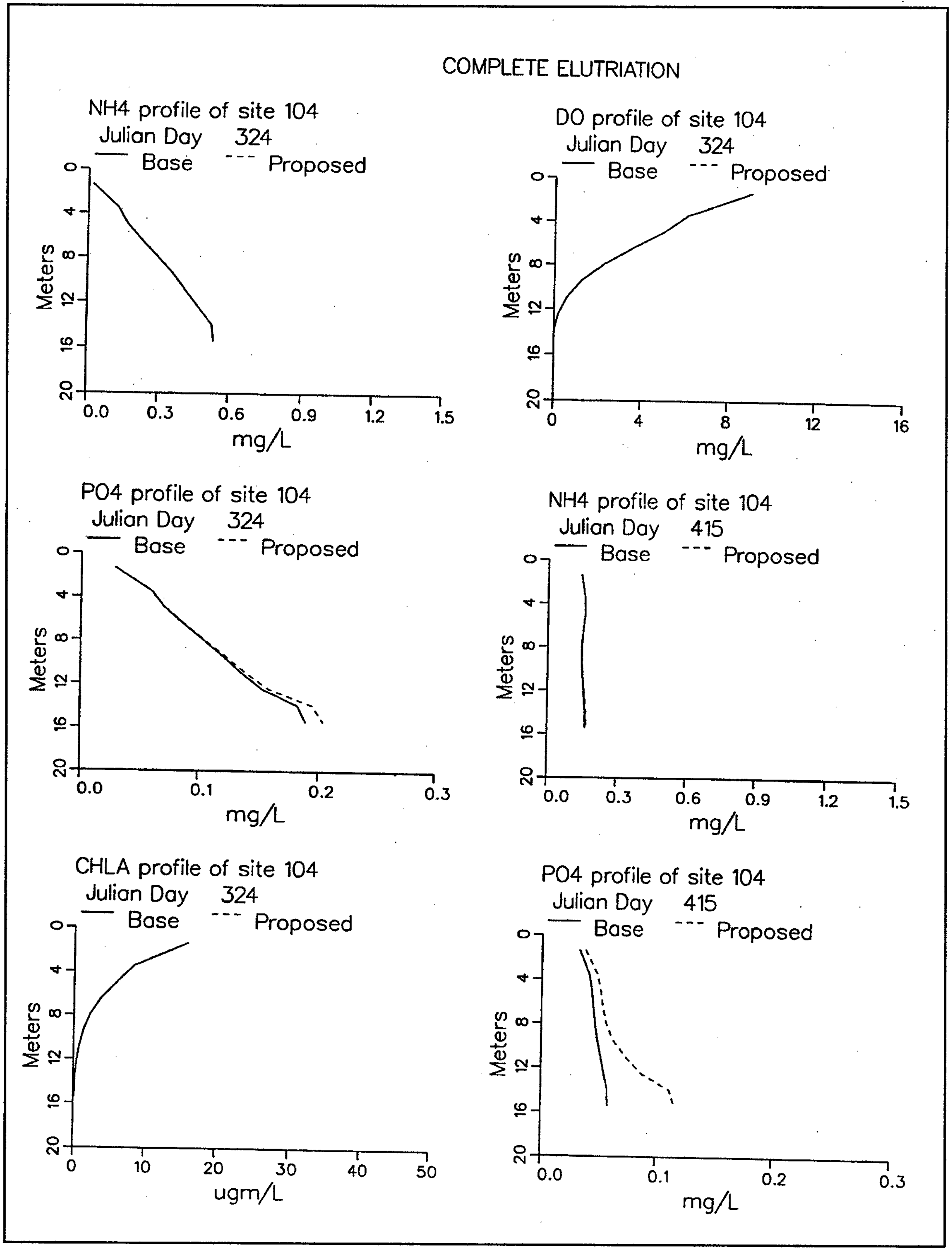

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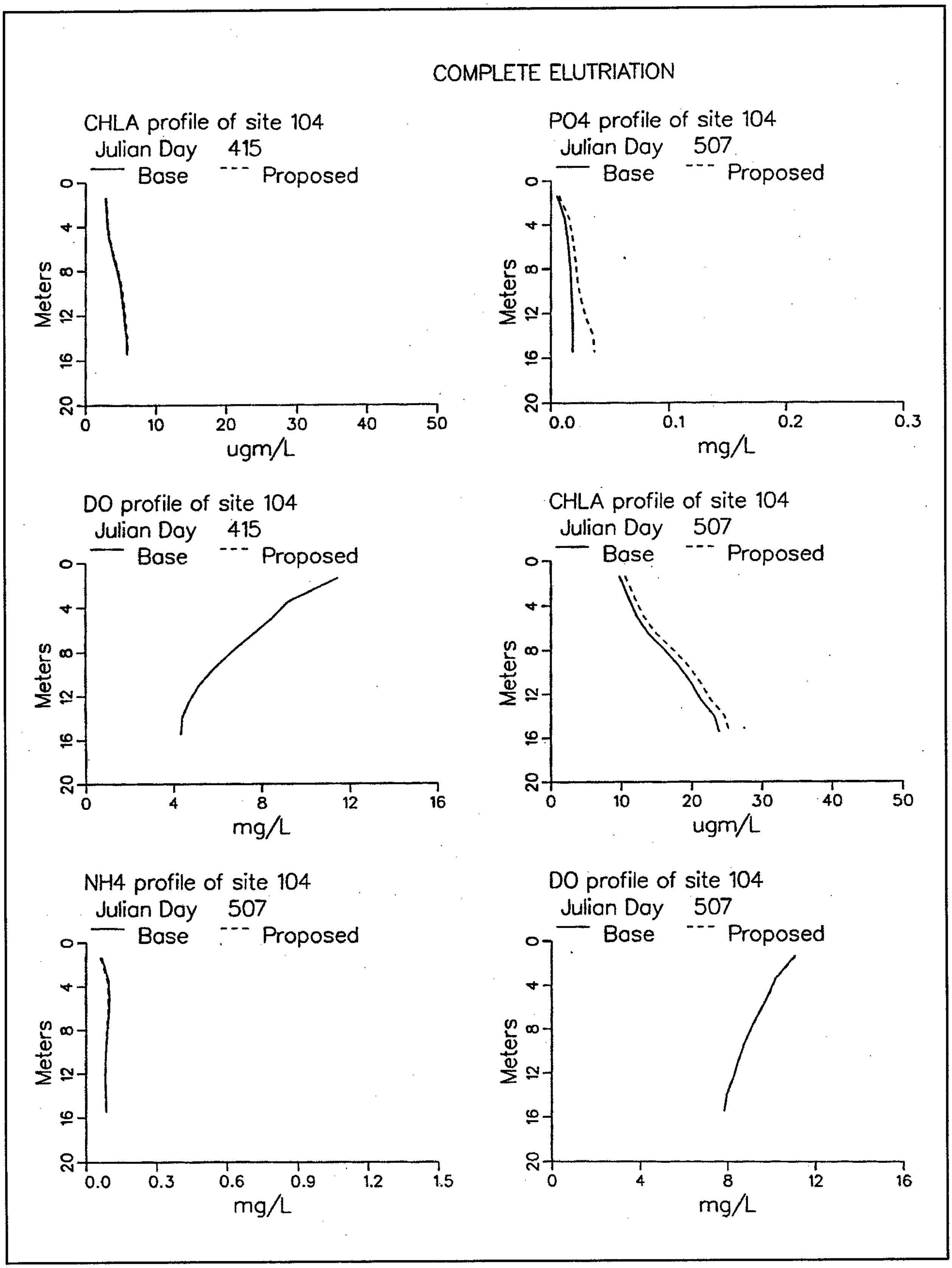

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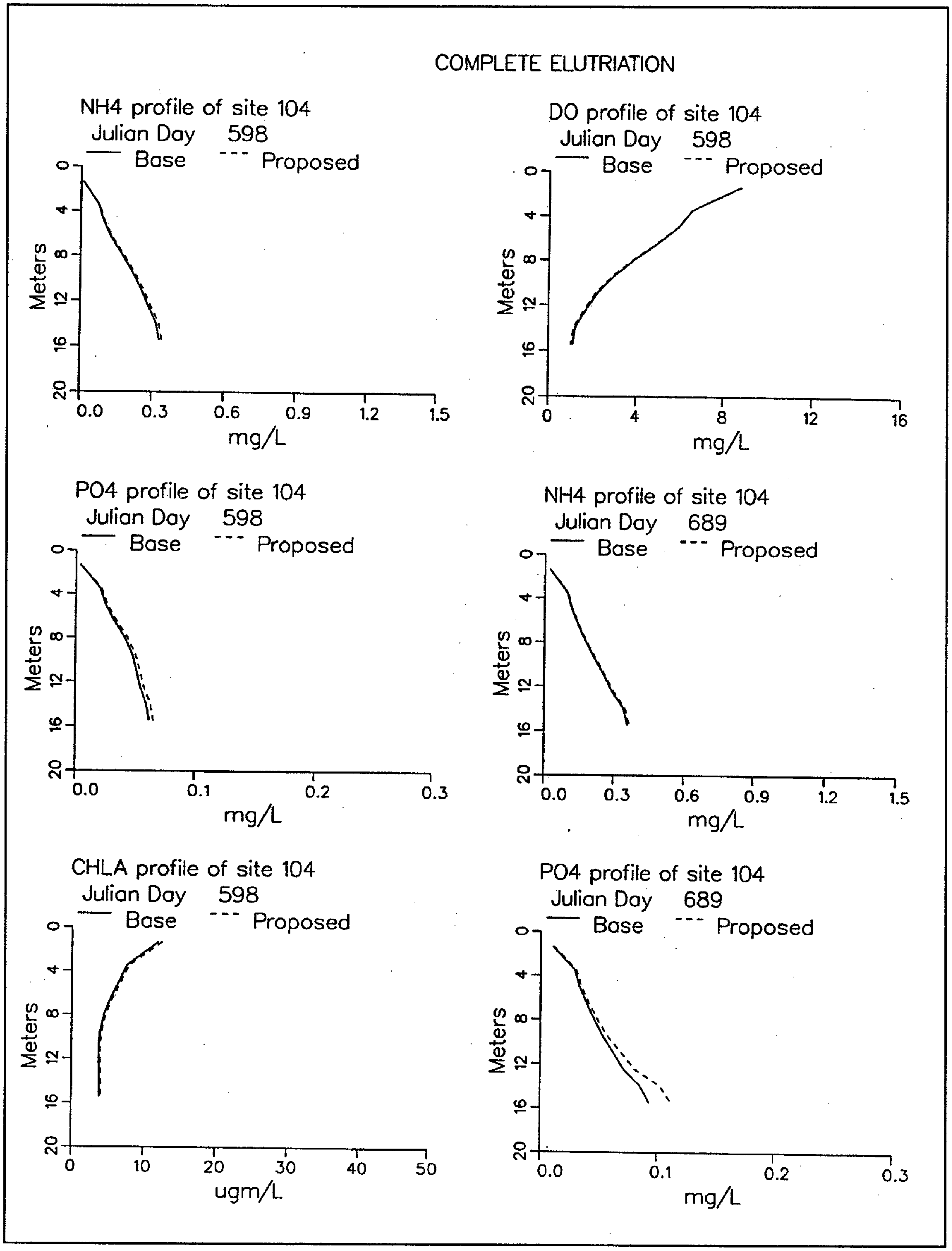

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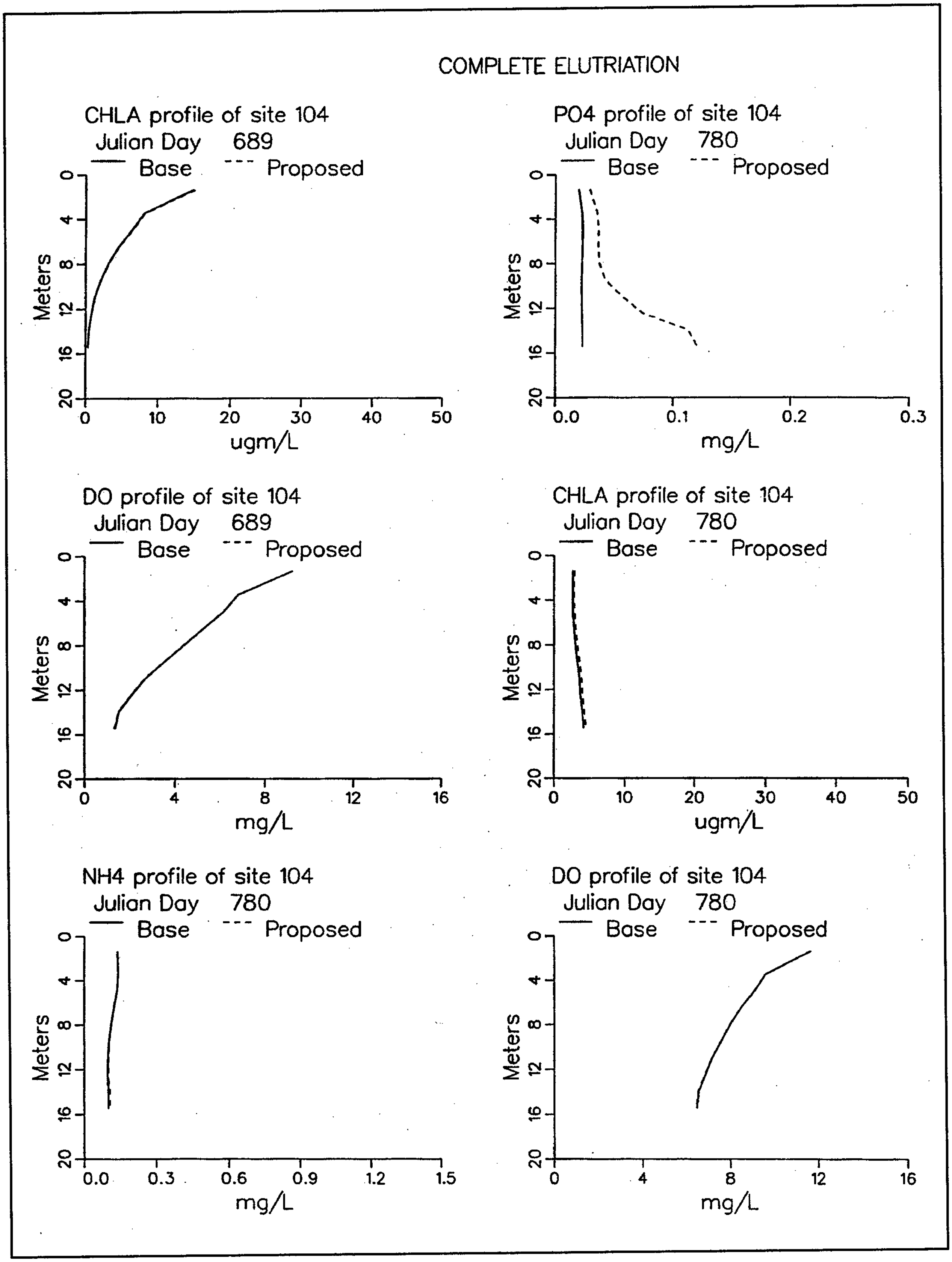

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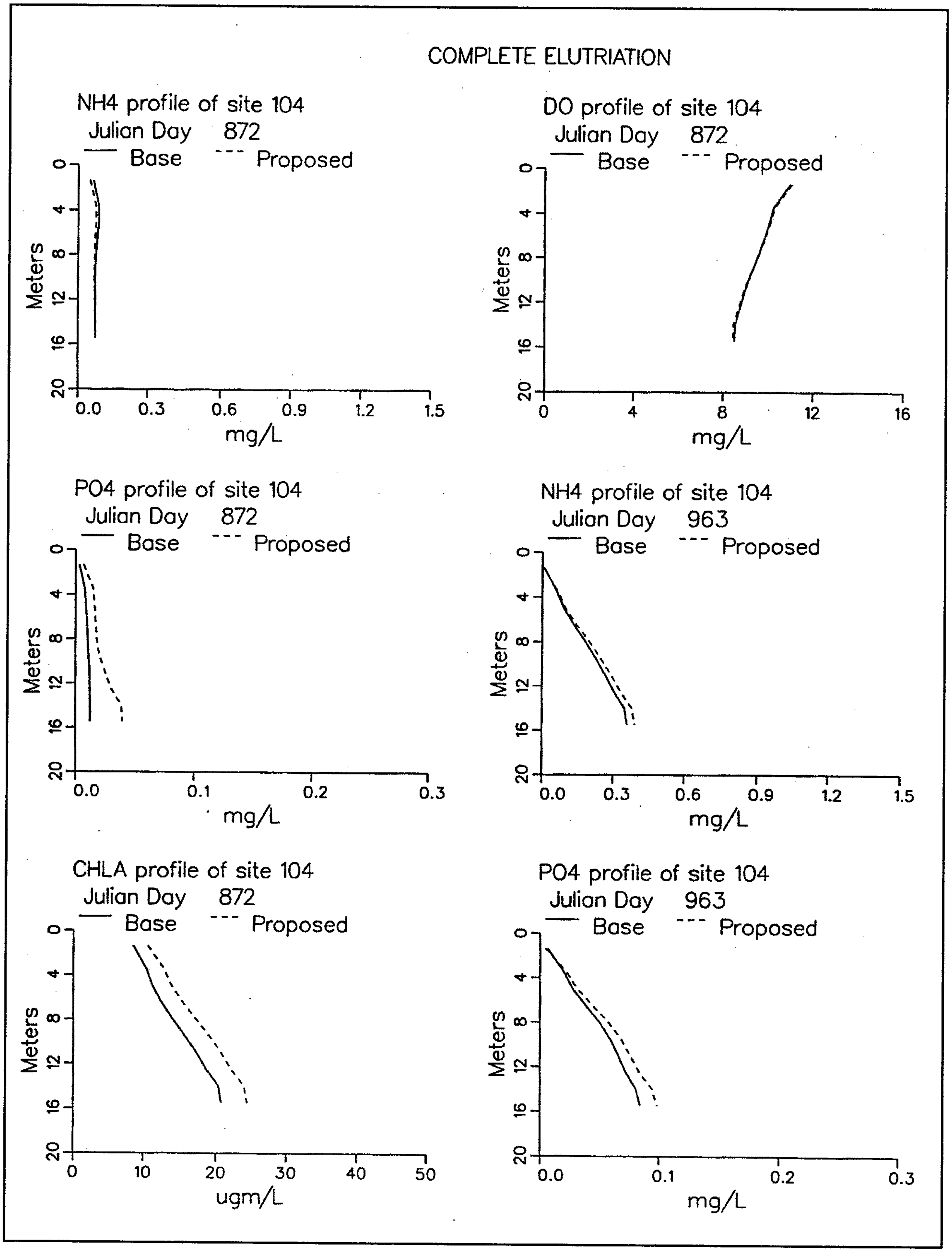

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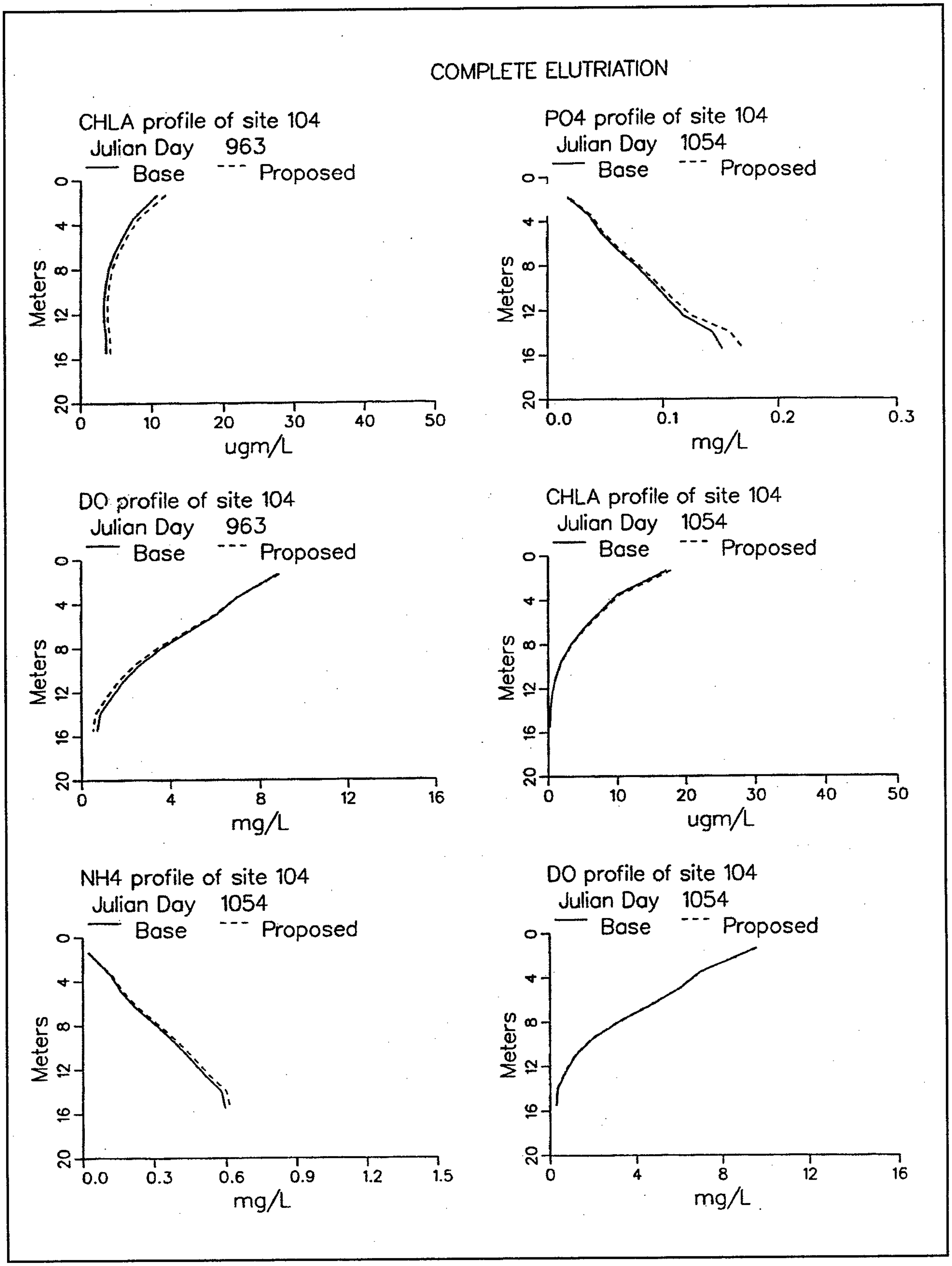

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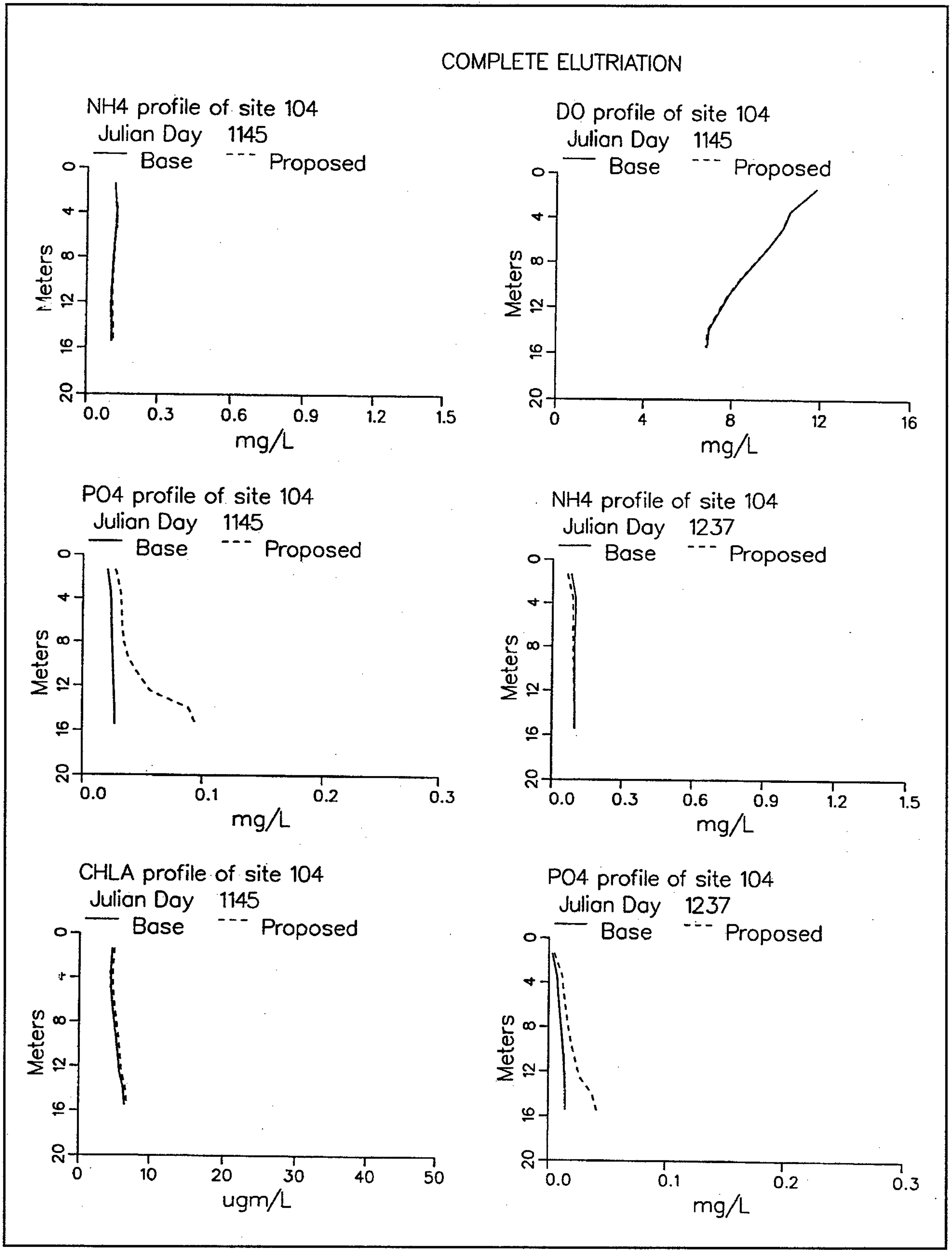

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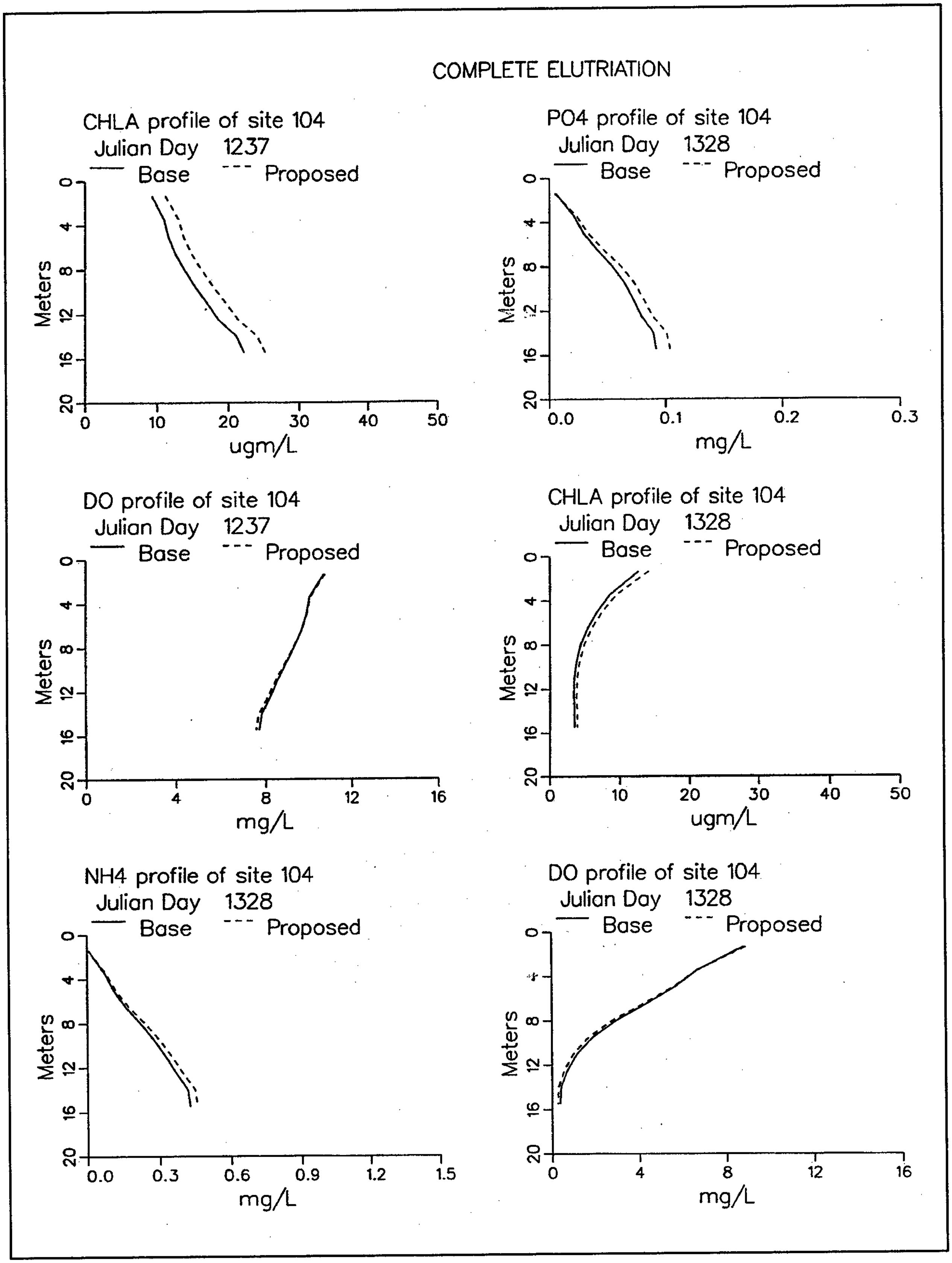

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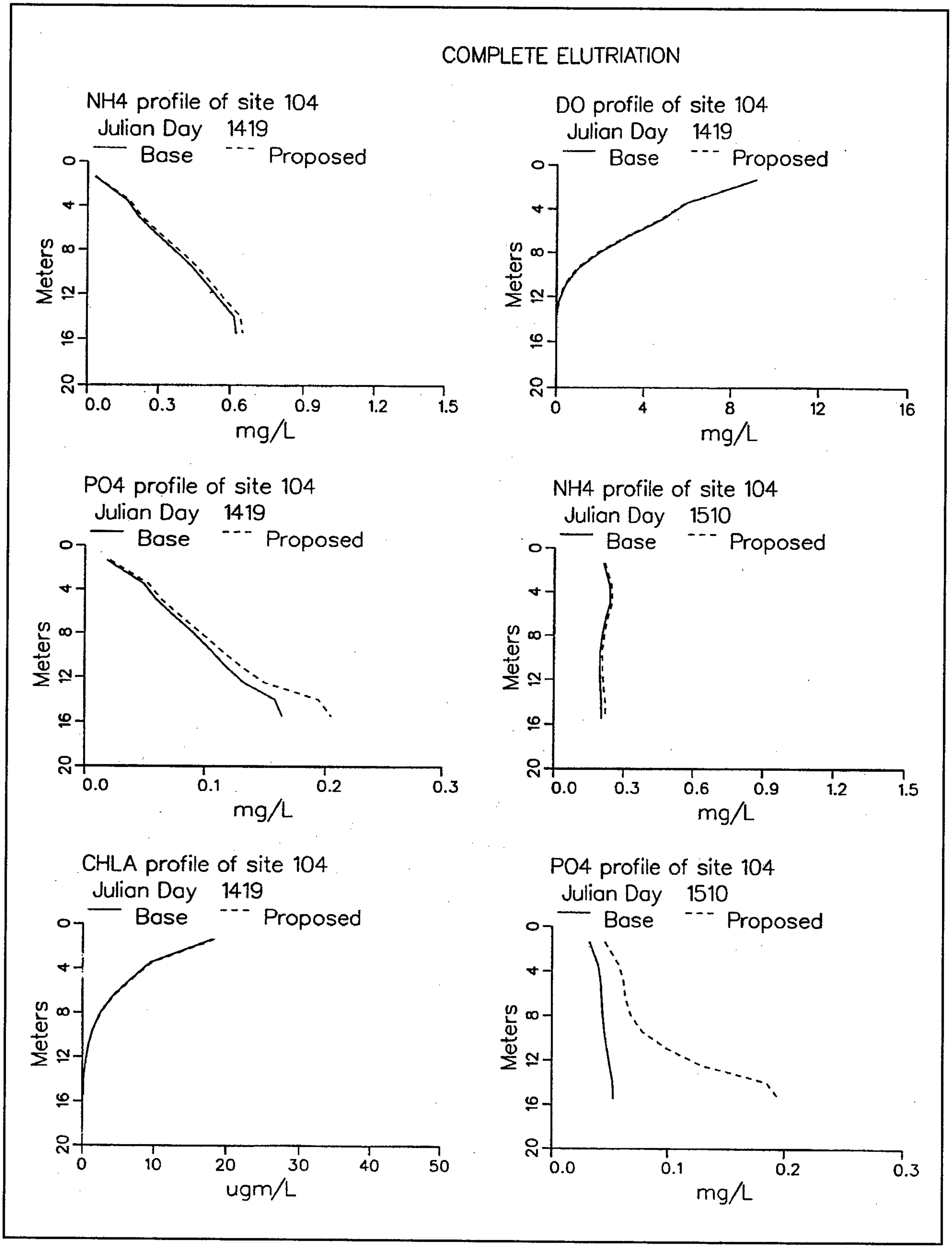
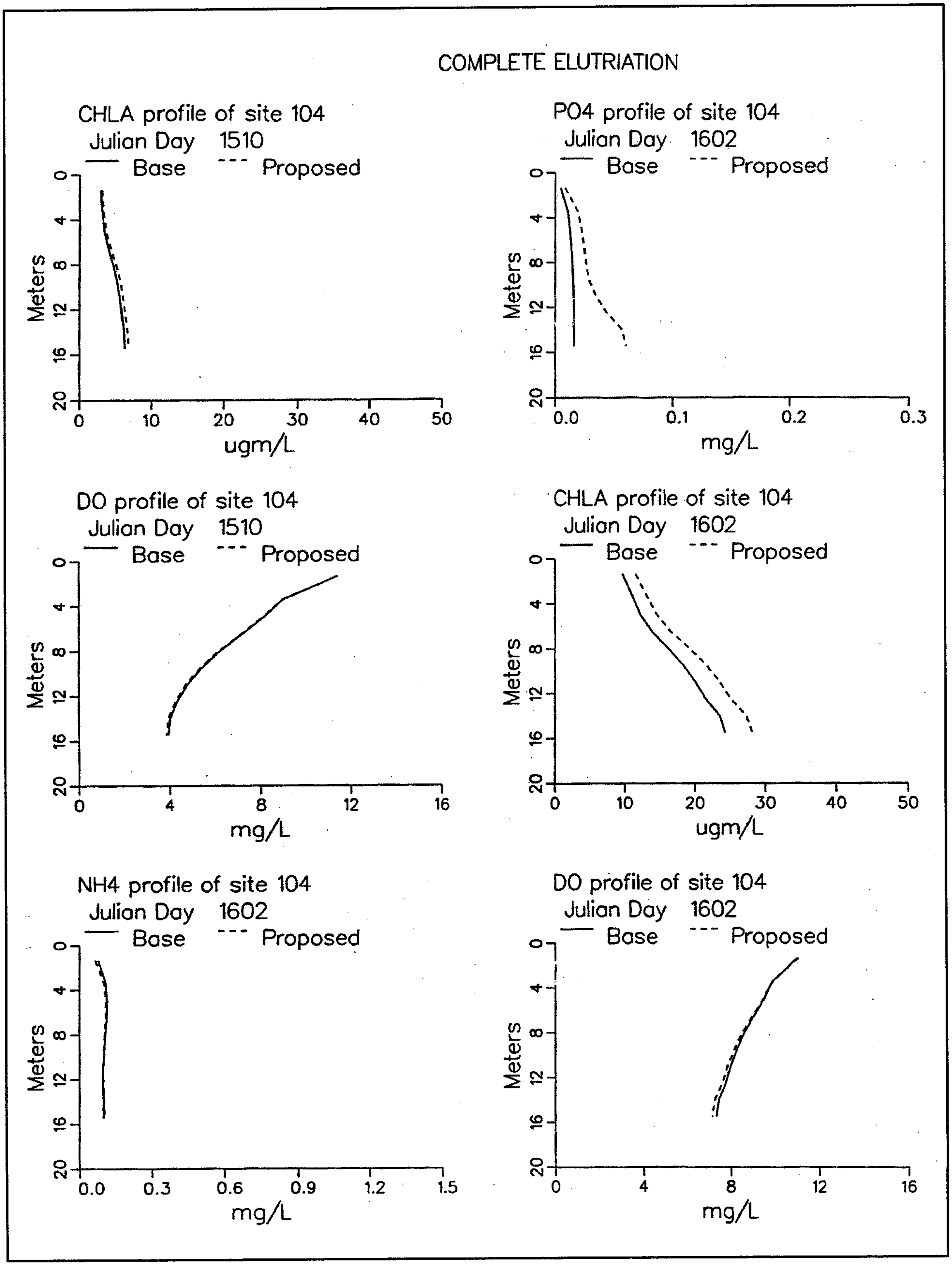


Figure 89. (Sheet 11 of 14)



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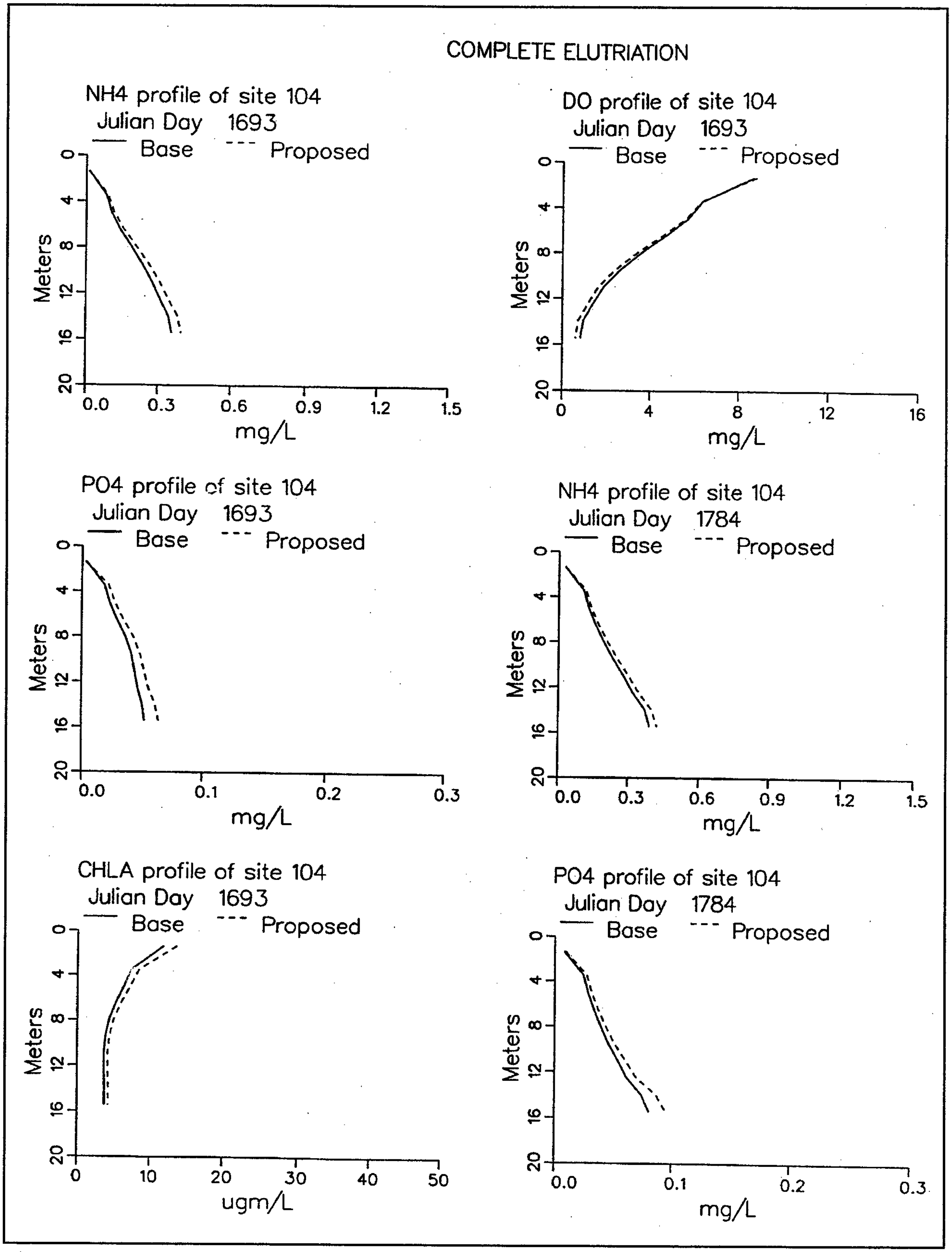

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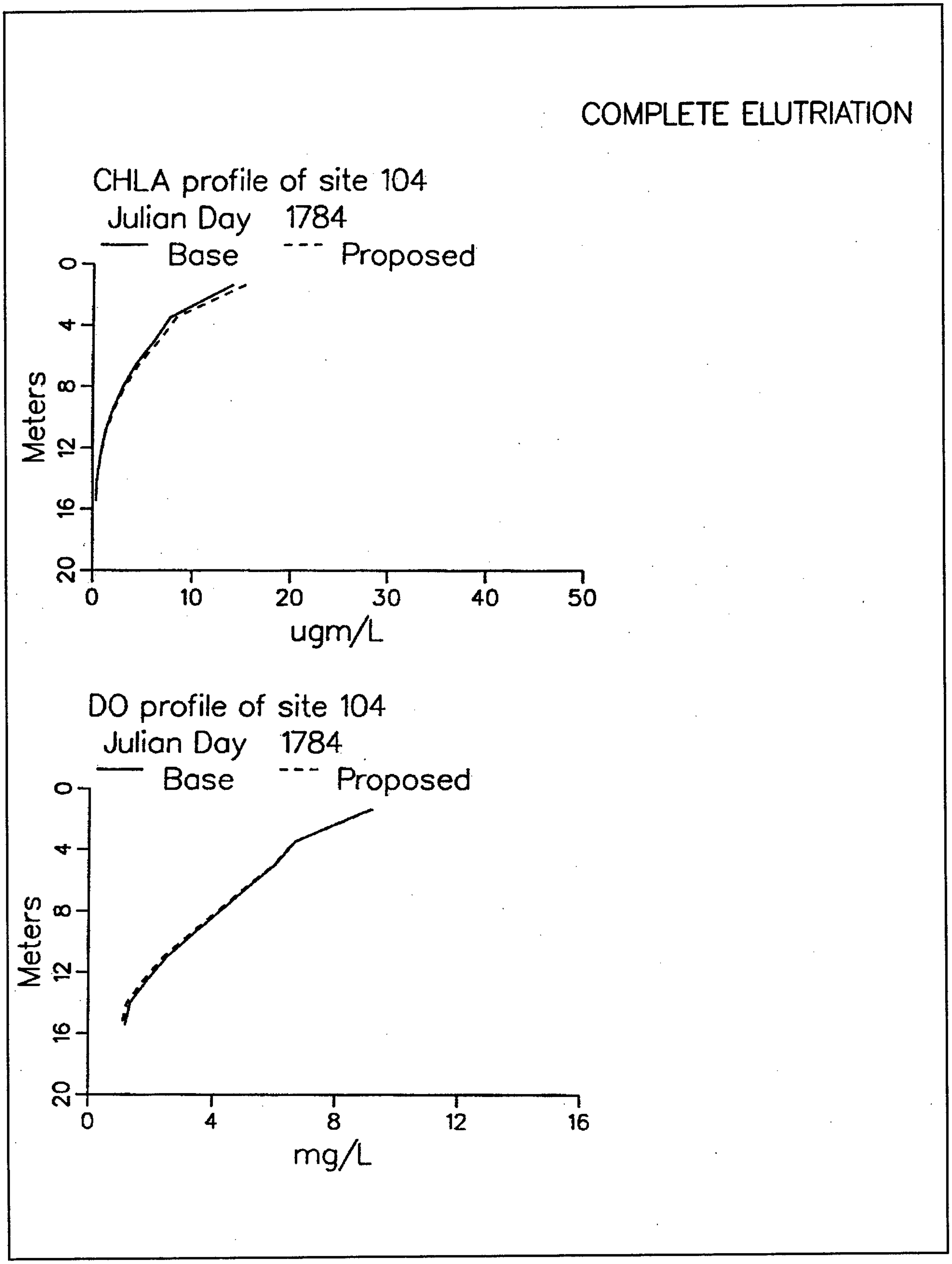

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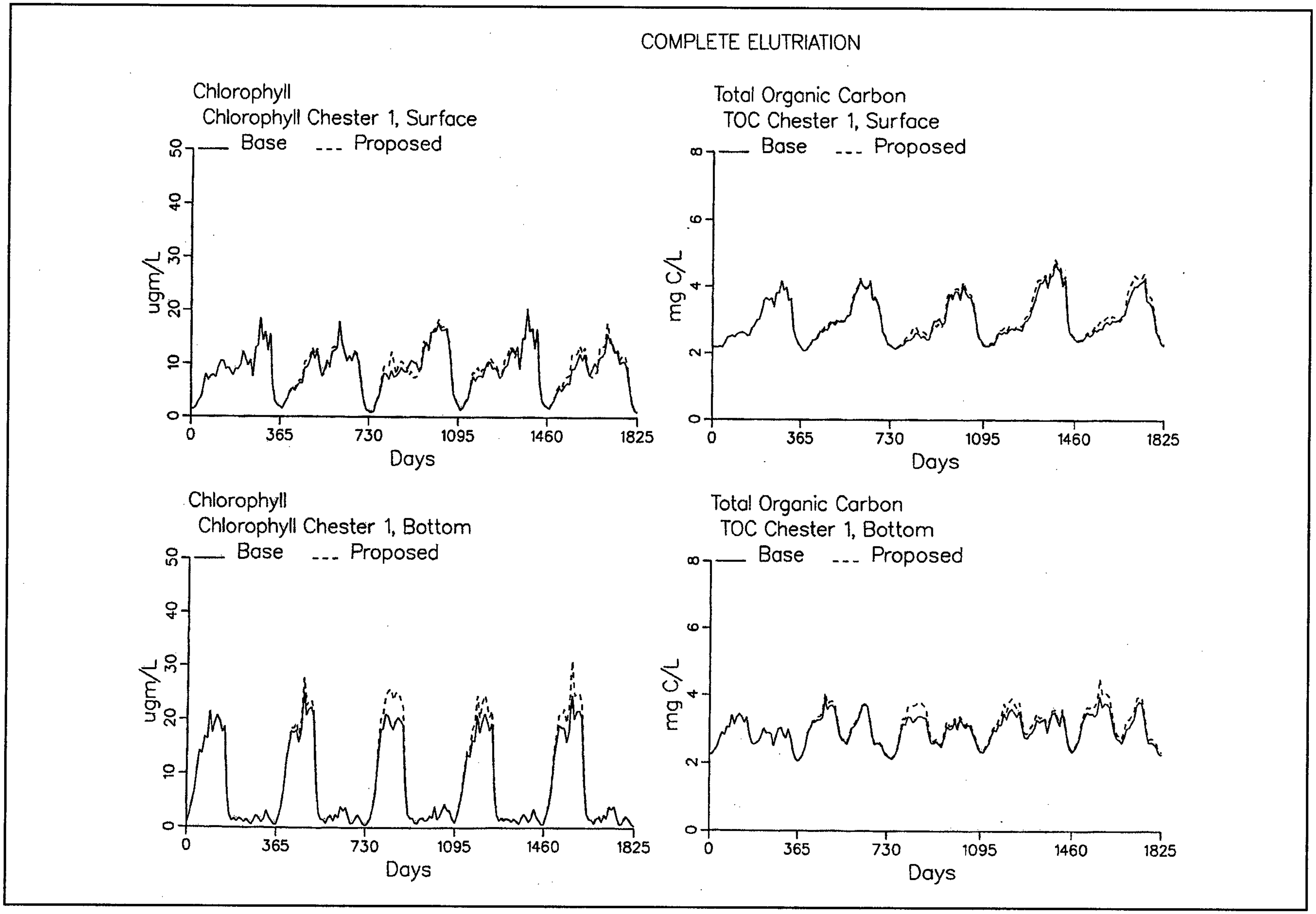


Figure 90. Times series of water quality at mouth of Chester River with complete elutriation (Sheet 1 of 5)

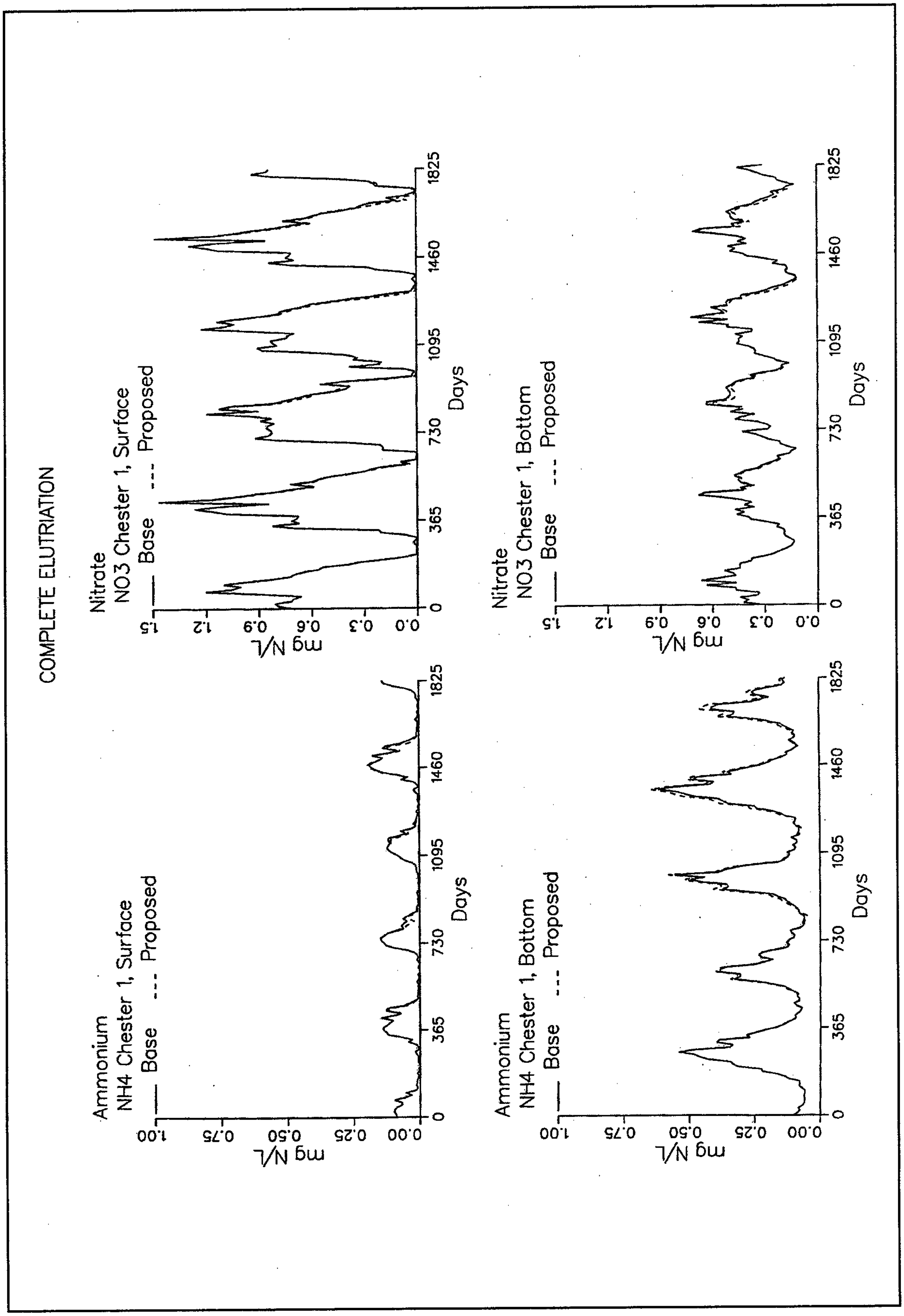
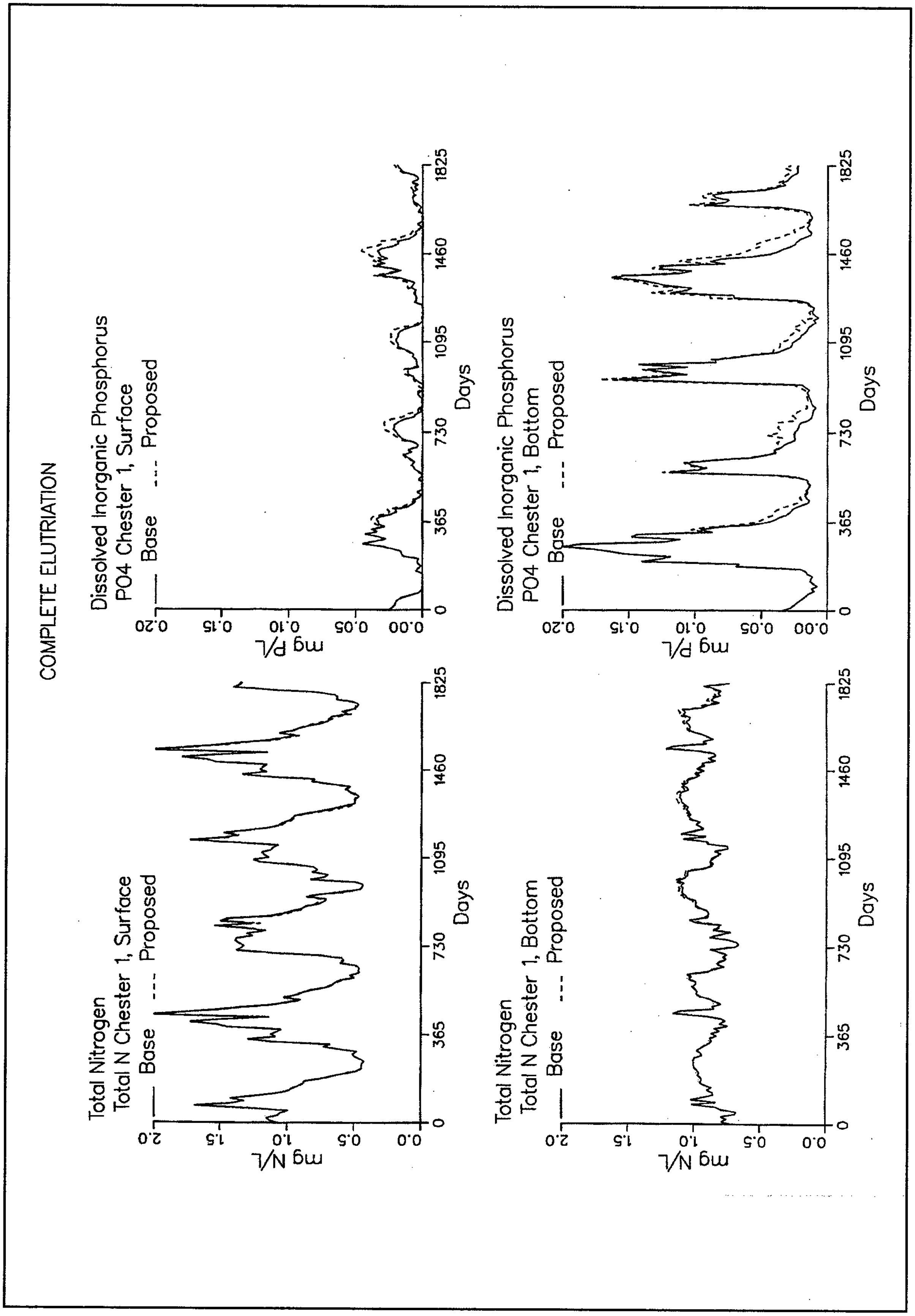


Figure 90. (Sheet 2 of 5)



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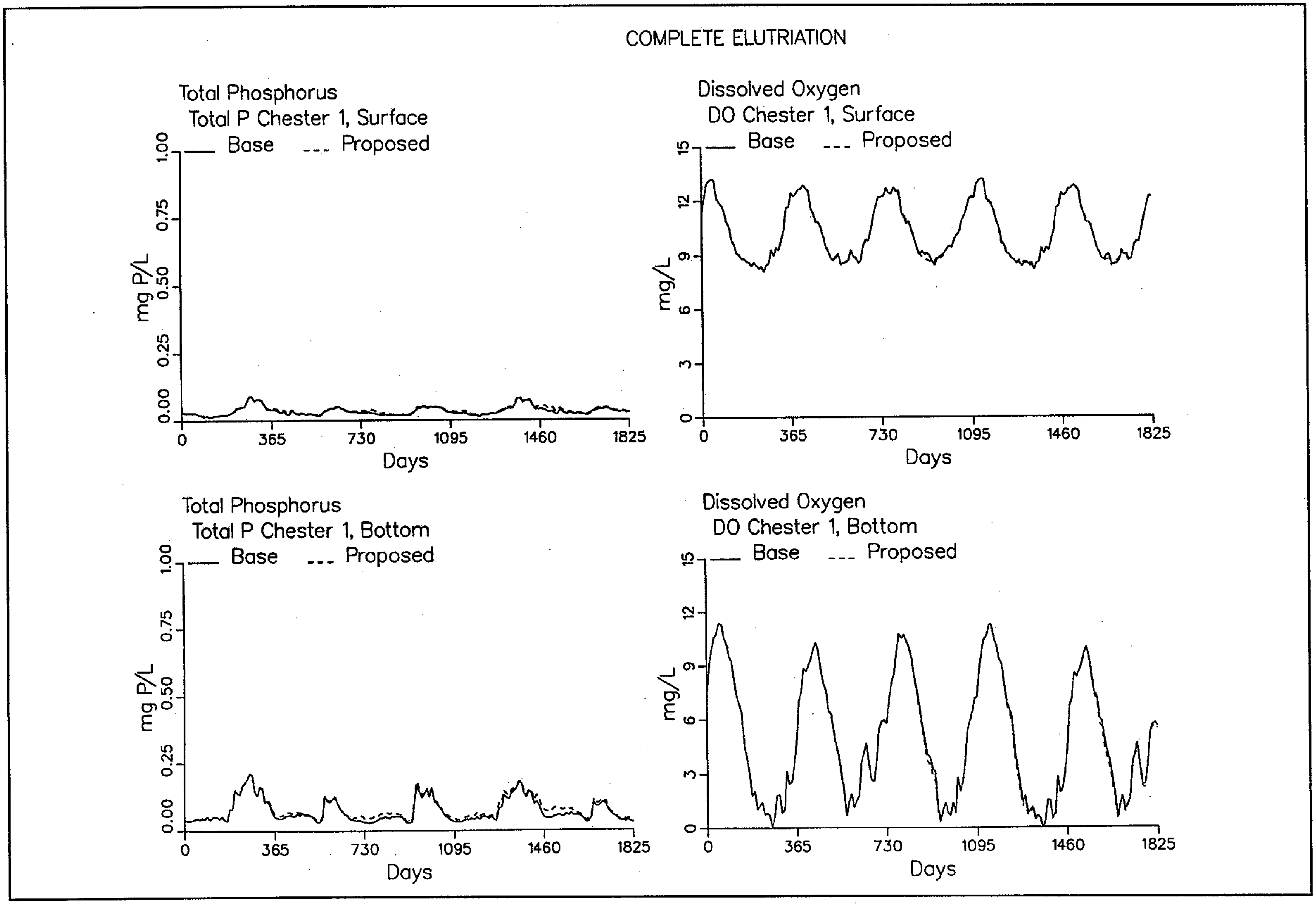


Figure 90. (Sheet 4 of 5)

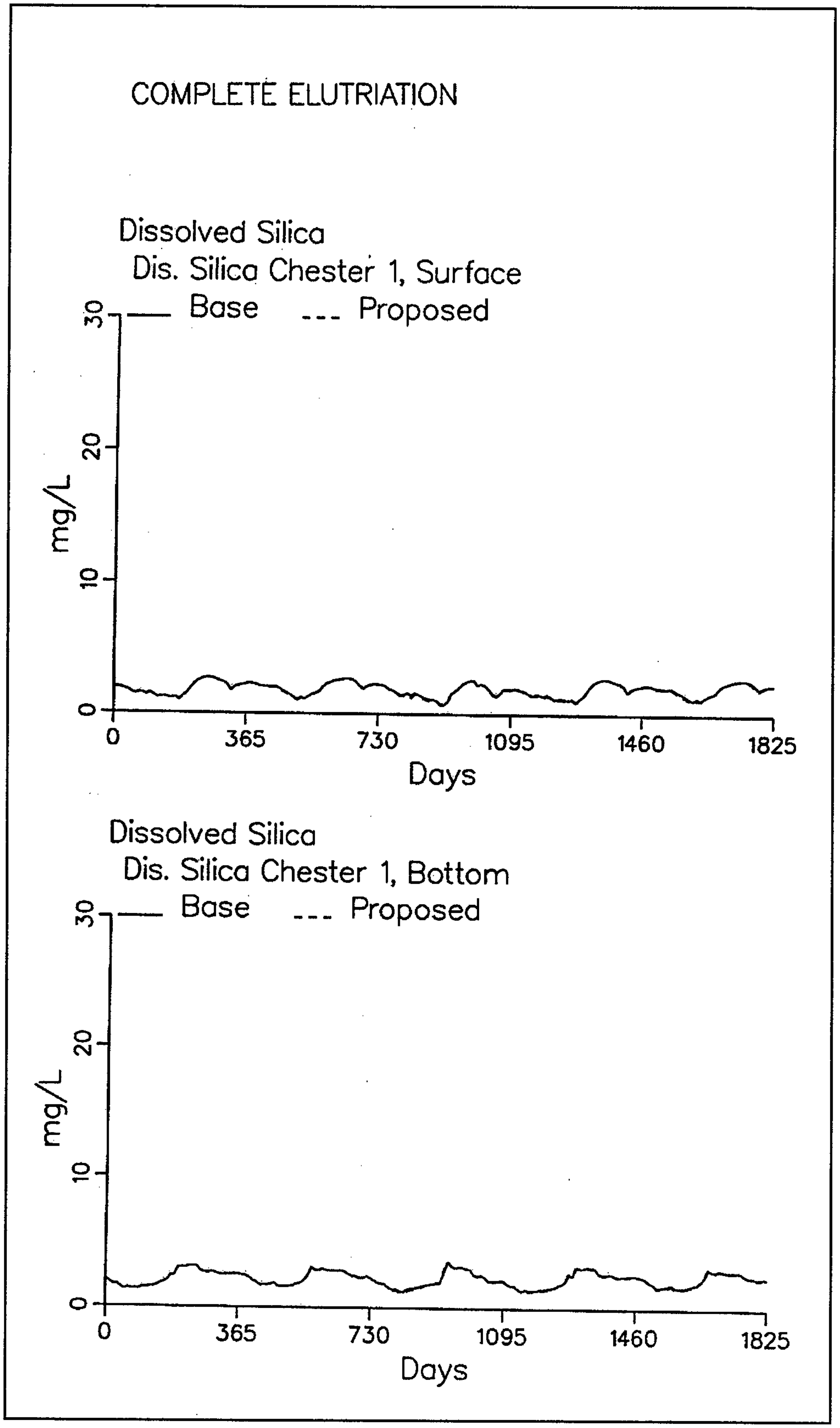


Figure 90. (Sheet 5 of 5)

on the spring algal bloom at the mouth of the Chester River. However, as previously concluded, the impact of placement of dredged material at Site 104 has a negligible impact on the dissolved oxygen of the bay's waters.

Comparison of Model Results with Boynton Data

Some water quality data have been collected by Boynton et al. (1996) at Site 104. Comparing model results with these data is of interest. For example, Boynton's measured sediment oxygen demand at Site 104 ranges from 0 to 0.94 g m^{-2} day $^{-1}$. This is in good agreement with the range of 0 to slightly over 1 g m^{-2} day $^{-1}$ computed by the model.

Boynton's sediment ammonium release ranges from 34 to 180 mg N m^{-2} day^{-1}. The model release is from 0 to 100 mg N m^{-2} day^{-1}. The model value of zero occurs during cold weather when Boynton took no measures since no flux occurs in cold weather. Converting the model units into Boynton's units, the maximum ammonium release is 300 μM N m^{-2} hr^{-1}. This maximum is in reasonable agreement with many of Boynton's measures. Only 20 percent of Boynton's measures exceed this value. In view of the variability of the measurement technique and the heterogeneous nature of sediments, the model results, which represent flux averaged over the bottom area of a cell and over a 10-day period, are valid representations of Boynton's set of observations.

Boynton's nitrate flux measures range from negligible release to an uptake of 70 mg N m^{-2} day^{-1}. The model agrees with the measures in that no significant release is ever computed. Model sediment uptake of nitrate is much less than Boynton's measures, roughly 10 mg N m^{-2} day^{-1}. The reason for the discrepancy is not clear. Possibly, the sediment diagenesis model simply does not do a good job predicting sediment-nitrate uptake. Since both predicted and observed nitrate uptake are negligible during summer months when algal production is potentially nitrogen limited, the discrepancy between model and observations is not of great importance.

Boynton's sediment-phosphorus fluxes range from negligible sediment uptake of phosphorus to a release of 40 mg P m^{-2} day^{-1}. The model values range from negligible sediment uptake to a release of around 50 mg P m^{-2} day^{-1}. These results indicate very good agreement between model and observations.

Boynton's silica flux measures indicate sediment release of 100 to 300 g Si m^{-2} day^{-1}. The model release ranges from roughly 50 to 400 g Si m^{-2} day^{-1}. The releases of 400 g Si m^{-2} day^{-1} are very short-lived. The majority of predictions lie in the range of 50 to 300 g Si m^{-2} day^{-1}. The lowest predictions occur during cold weather when no measures were collected. For most of the warm-weather period, computed maximum silica releases are in good agreement with Boynton's maxima.

No Elutriation versus Complete Elutriation

The impact on Site 104 water quality of both no elutriation and complete elutriation of the dredged material that might be placed at the site was computed to be negligible. Complete elutriation did slightly stimulate the spring algae bloom because of the release of phosphorous when the nutrient was required by the algae. Consequently, no elutriation is preferred from a water quality standpoint.

11 Other Issues

Impact of Placement on Tidal Flow at Site 104

As previously noted, time series data from the CH3D-WES simulations at the three points shown in Figure 26 are given in Figures 27-31 for bottom shear stress and Figures 32-36 for depth-averaged current. The largest single year change in Site 104 flow conditions because of proposed dredged material placement occurs in response to Year 1 placement. Comparing Figure 32 (preplacement currents) to Figure 33 (postplacement Year 1 currents) shows that the depth-averaged current was not significantly affected (less than 2 percent). However, a 15-percent reduction in bottom-shear stress was computed for flow point No. 15, while the shear stress increased by 15 percent at flow point No. 1 in response to year 1 placement (compare Figures 27 and 28). Bottom-shear stress at flow point No. 25 was reduced by less than 2 percent. The above findings indicate that the "berm" feature created by the Year 1 placement reduced the bottom current (indicated by bottom-shear stress) at flow point No. 15 by impeding flow through the longitudinal depression of Site 104, although the impact on flow for the overall water column (indicated by the depth-averaged current) was minor. The fact that dredged material placed during Year 2 (one should see Figure 8 for placement locations) experienced less "long-term loss" than was predicted for Year 1 (Table 16) is due to Year 2 material being placed behind the "berm" created by Year 1 placement. A more in-depth analysis of the full 3-D flow fields is required to make definitive statements about the overall impact of the dredged material placement on tidal currents since placement mounds can cause a redistribution of flows over the site. An inspection of Figures 55 and 56 imply that this is the case at Site 104. In addition, the results shown in Figures 55 and 56, which show only the impact on erosion of filling the site, imply that the potential for erosion slightly increases as the site fills. This in turn implies that in general there must be an overall increase in bottom-shear stress over the site as it fills with the placed material.

Impact of Placement on Salinity

The placement of approximately 18 million cu yd of dredged material at Site 104 will result in a loss of depth along a route for salt migration into the

upper bay. Thus, it is possible that salinities in the upper bay will be impacted. With the decreased depth, the propagation of higher bottom salinities will be impeded and upper bay salinities may decrease. Figures 91-94 show computed salinities from CH3D at four locations (Figure 3) before any placement of dredged material and then the impact on those salinities after the fourth year of placement. It can be seen that the long-term impact of filling Site 104 is to slightly decrease salinities in the upper bay. However, events exist where the impact is to temporarily increase the salinity. The reason for this is unknown. An in-depth analysis of the 3-D hydrodynamics would be required. For example, animation of a 3-D graphical representation of the salinity field rather than time series plots at a few locations is needed. In addition, computations such as determining the total change in the salt volume north of Site 104 should be made.

Impact of Sea-Level Rise

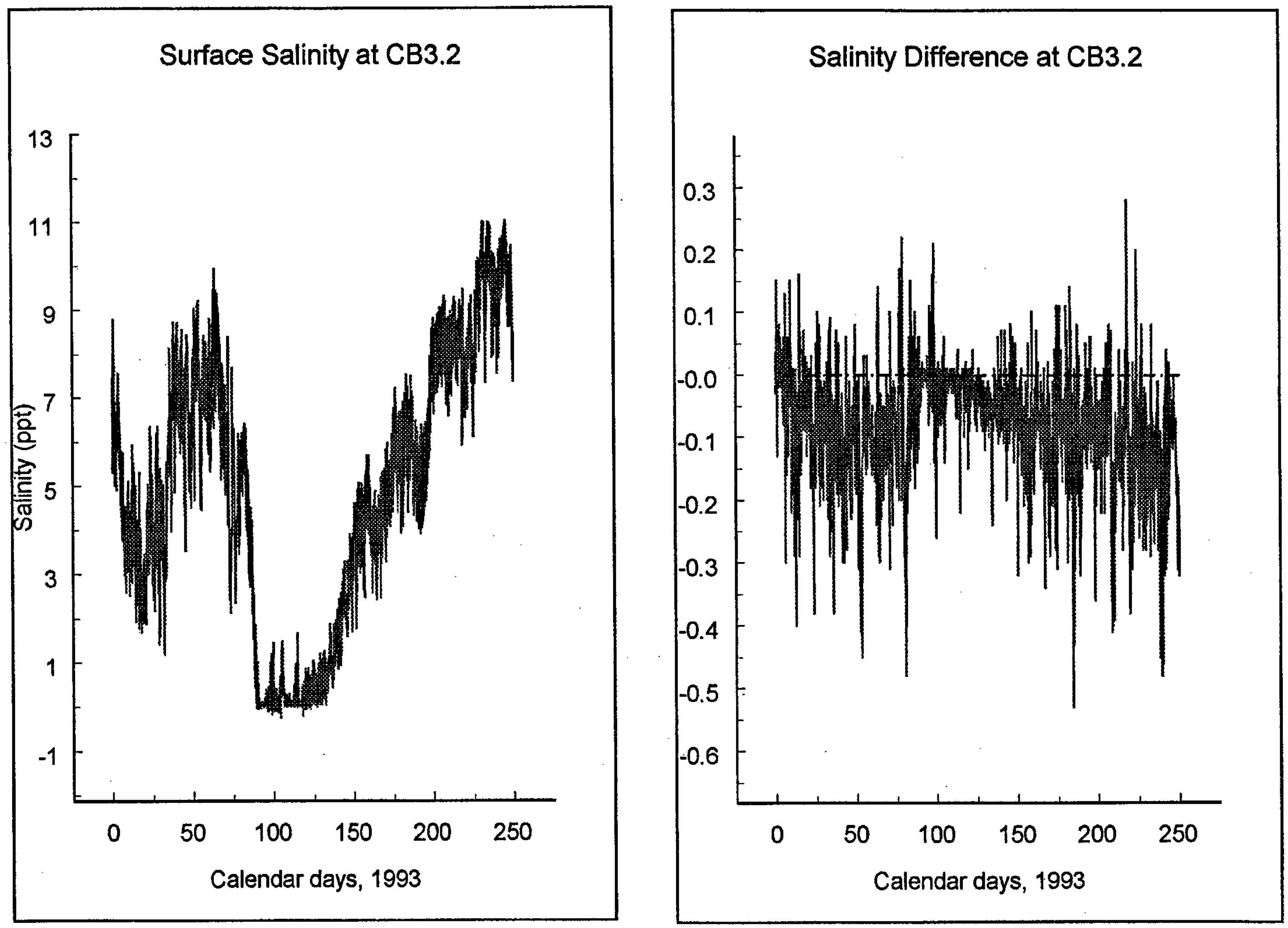
The impact of a sea-level rise, combined with the placement of dredged material at Site 104, depends on the magnitude of the sea-level rise. A sea-level rise will increase the water depth in the upper bay and will also result in a greater intrusion of salinity into the bay. A previous simulation with the full bay 3-D hydrodynamic model showed that a 1-ft rise in the water surface at the bay mouth would result in an increase in water depth of about 0.9 ft at the bay bridge. However, the C&D Canal was assumed to be closed in that simulation. To adequately address this question, a coupled full Chesapeake and Delaware Bays model is needed. Such a model does not currently exist.

Impact of Extreme Events

As part of this study, Moffatt & Nichol Engineers analyzed historical records of environmental forcings, e.g., winds. An inspection of their analysis lead to the conclusion that it would take events with a greater than 25-year frequency of occurrence to create wave conditions that would impact erosion of material placed below -45 ft MLLW at Site 104. Thus, the impact of waves on bottom-shear stresses was not included in the MDFATE simulations. If wave conditions corresponding to extreme events such as hurricanes had been included, erosion would have been greater.

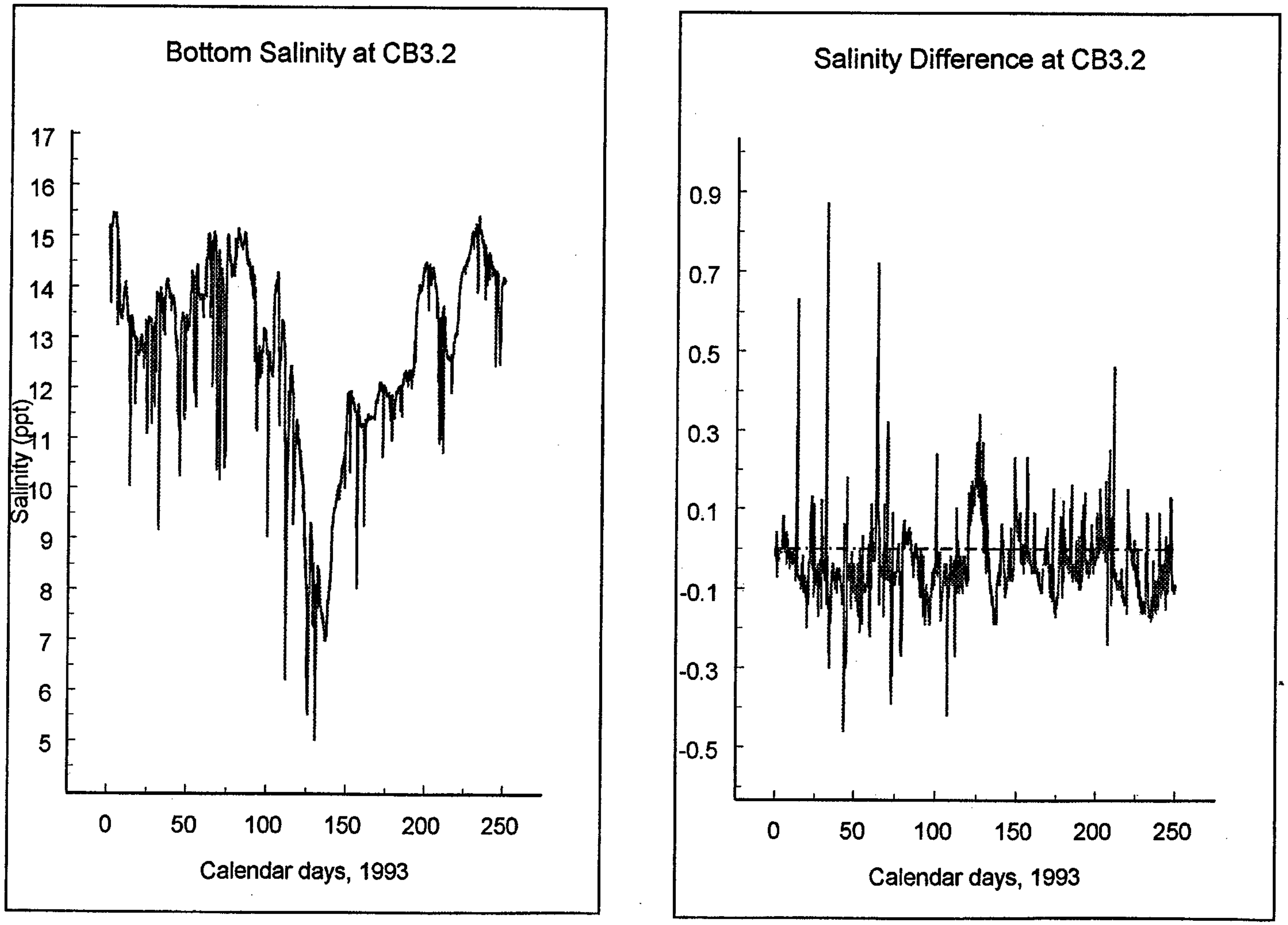
Impact of Residual Currents at Site 104

As previously noted, tracer simulations were made in the water quality model. These were made using 1986 hydrodynamics to demonstrate the long-term transport near the bottom of the upper Chesapeake Bay because of gravitational circulation. Figures 95-96 show that a tracer injected into the water column near the bottom at Site 104 experiences net transport to the north.



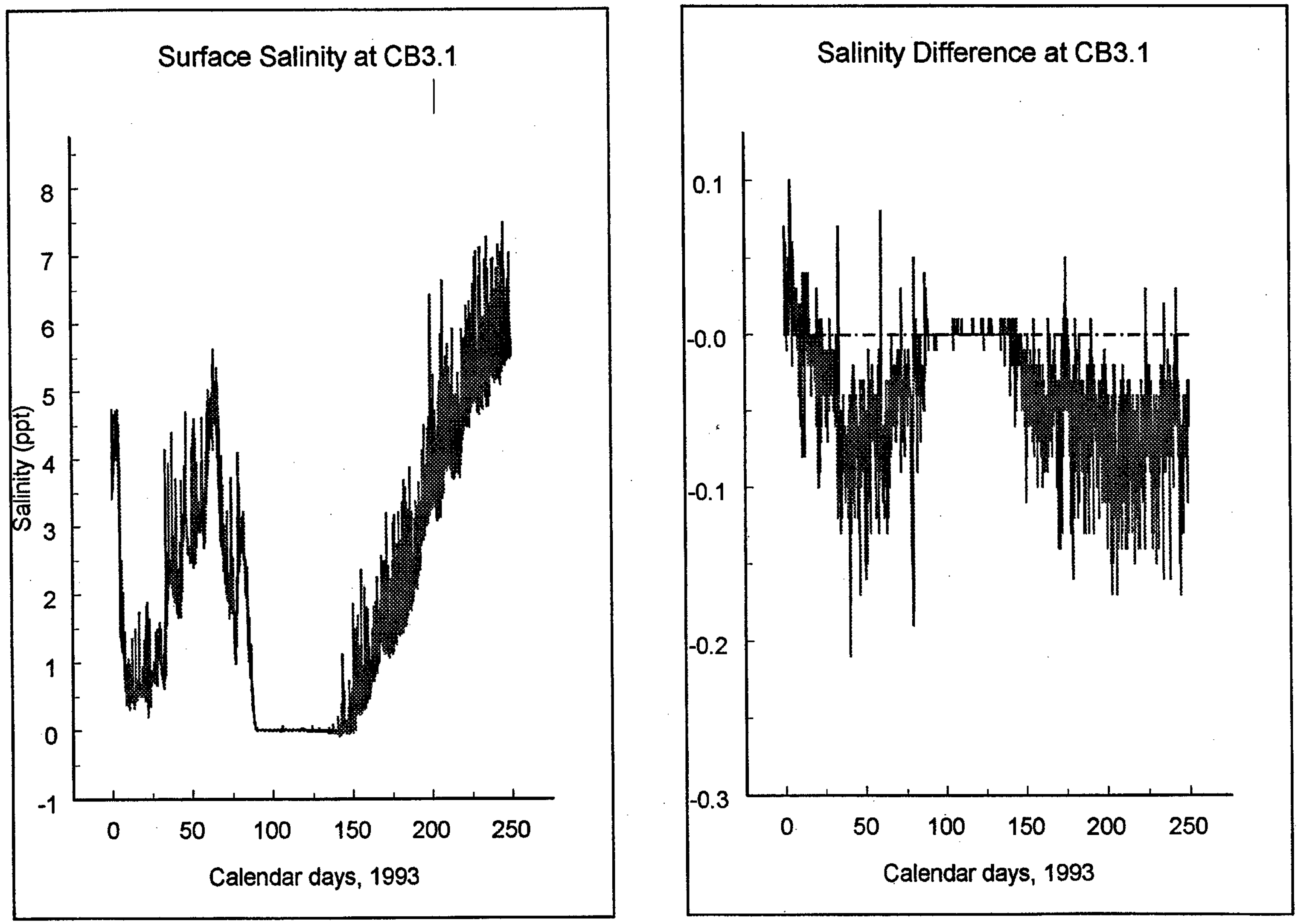
a. Surface

Figure 91. Impact on salinity at CB3.2 (Continued)



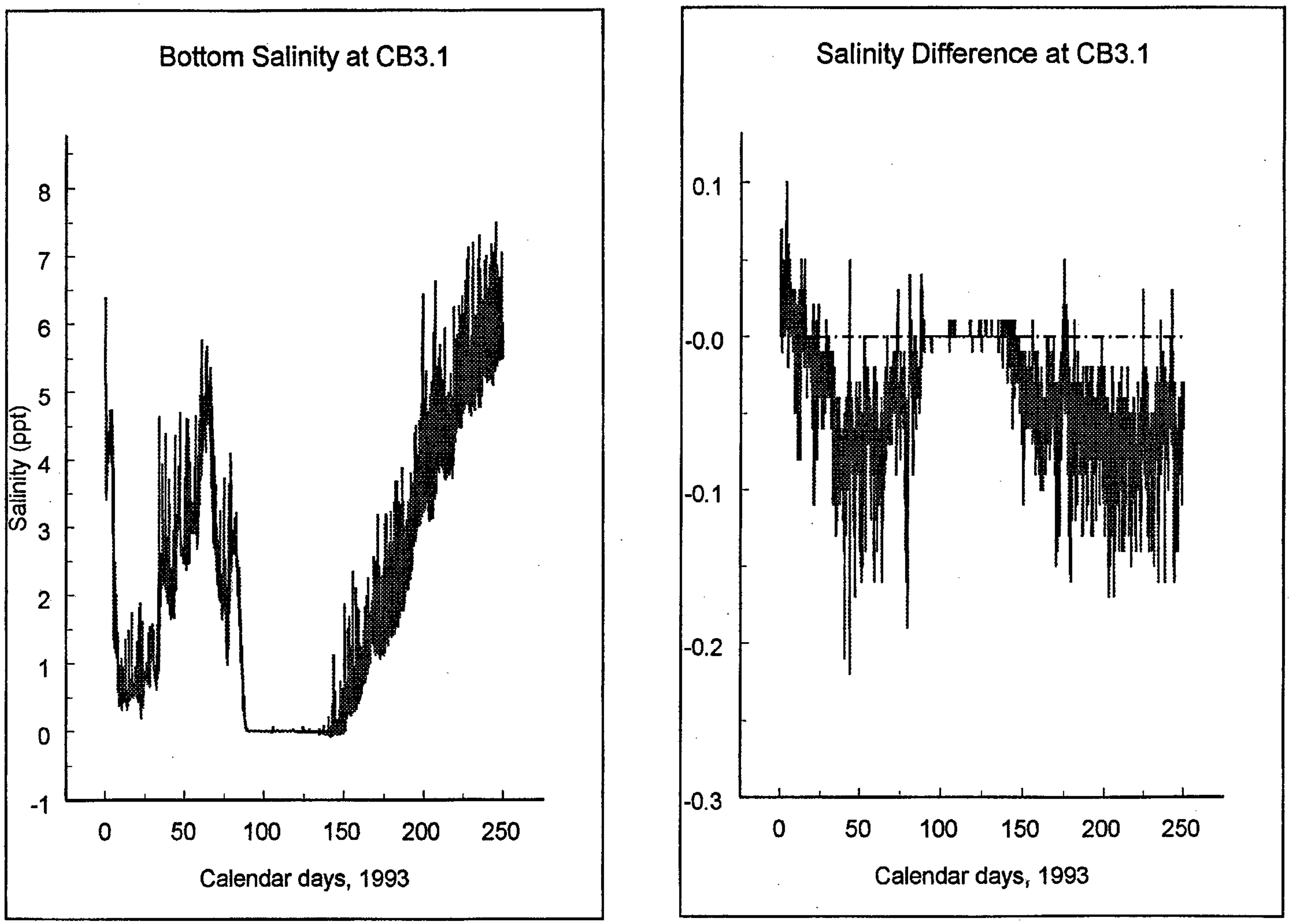
b. Bottom

Figure 91. (Concluded)



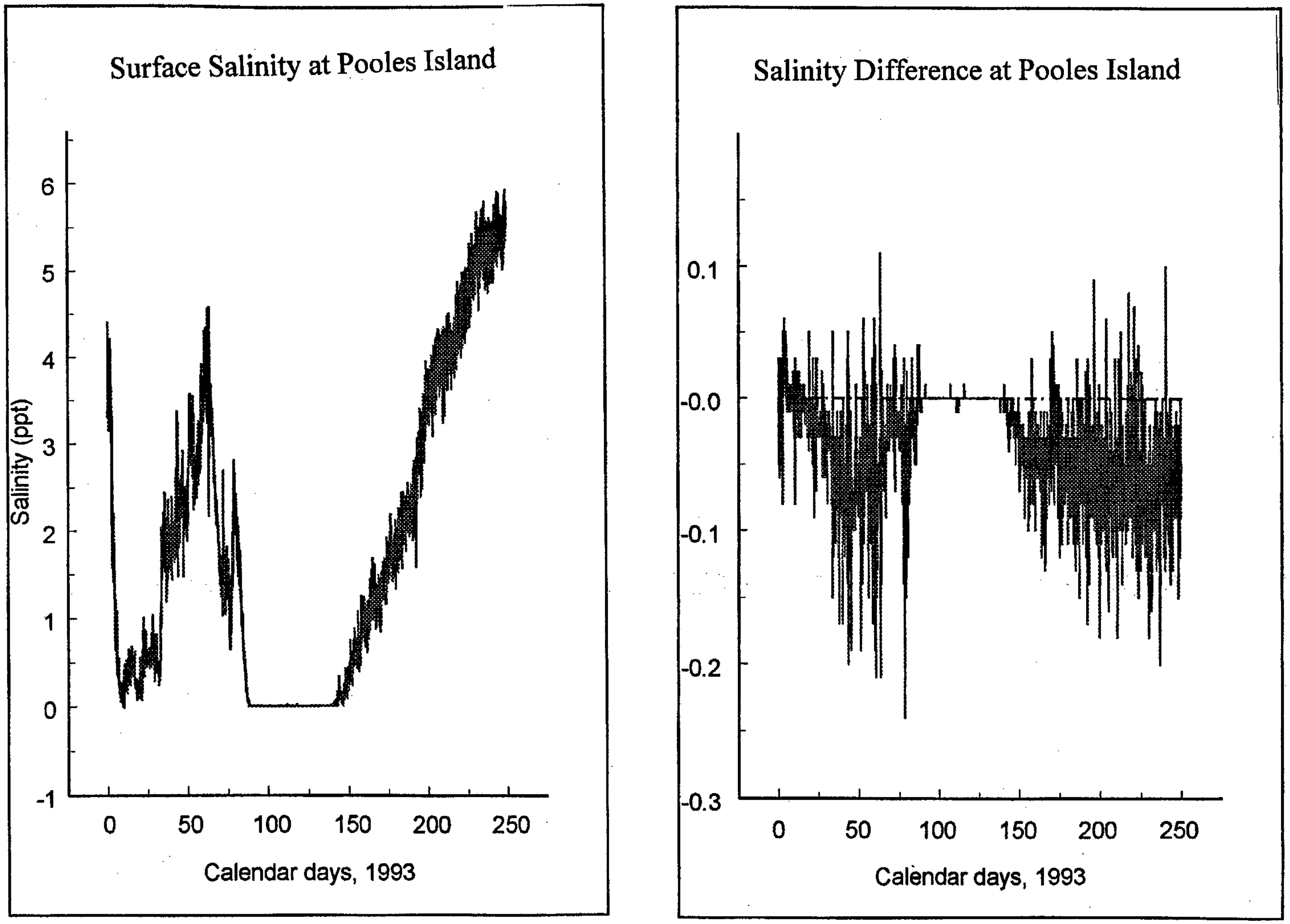
a. Surface

Figure 92. Impact on salinity at CB3.1 (Continued)



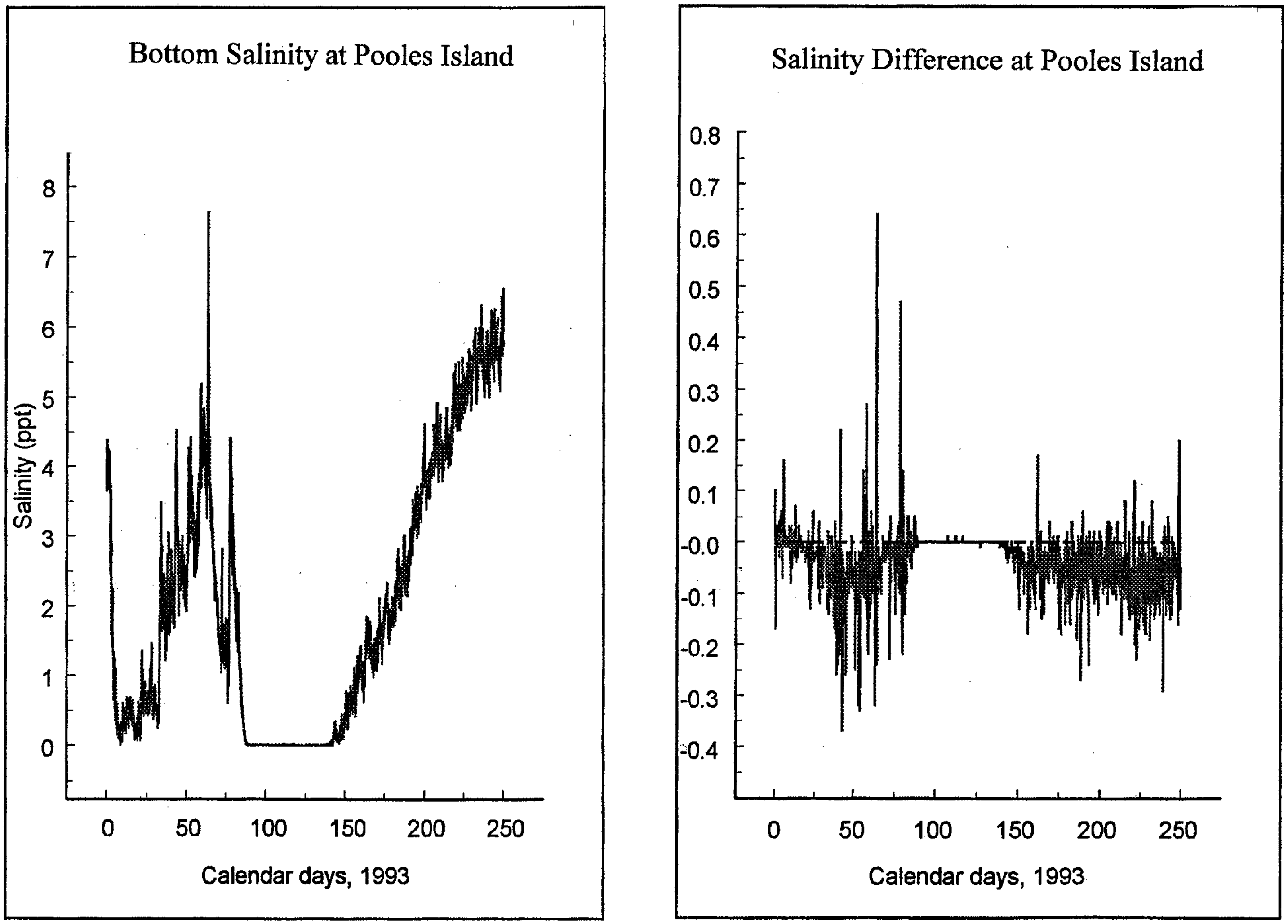
b. Bottom

Figure 92. (Concluded)



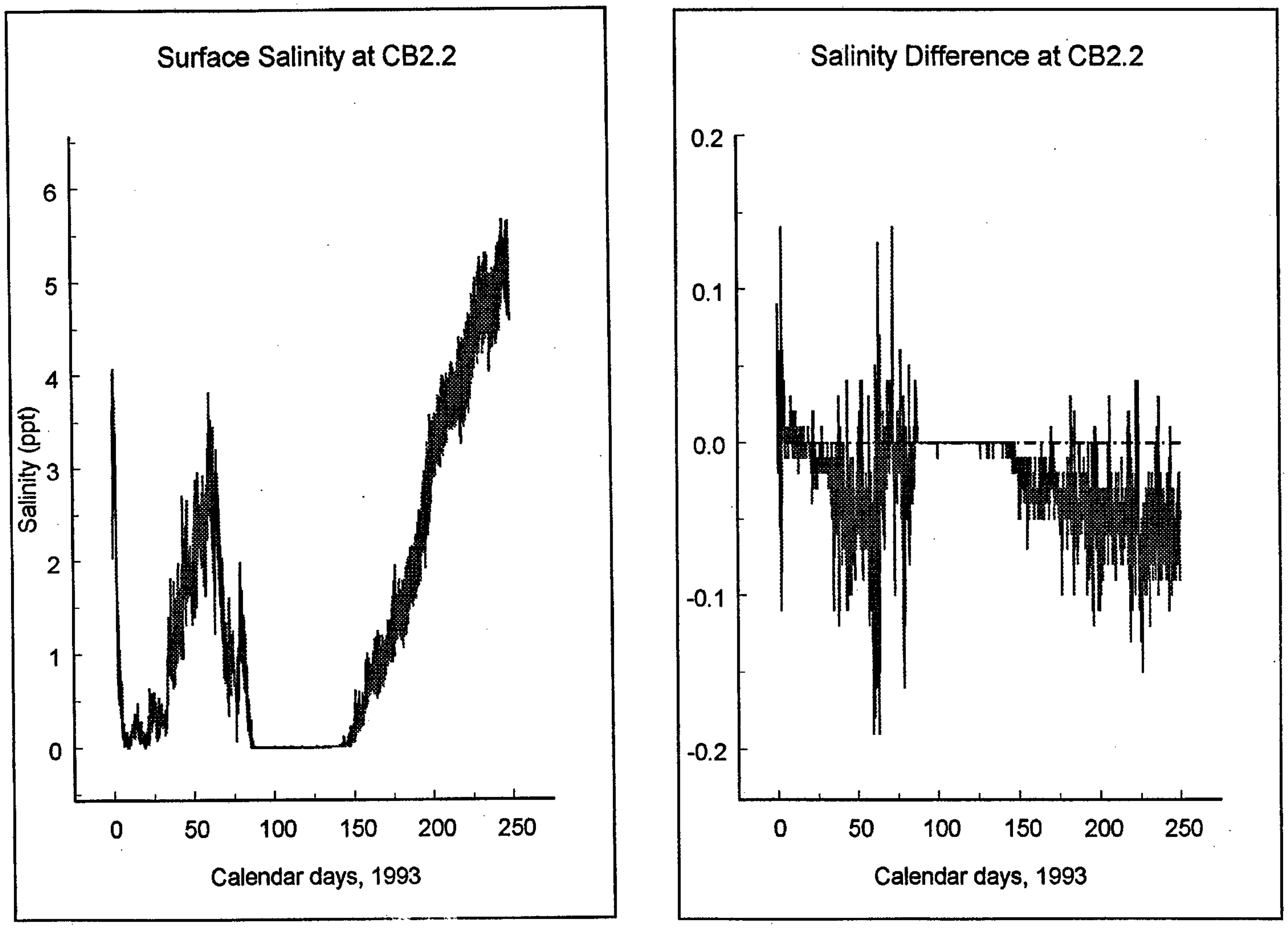
a. Surface

Figure 93. Impact on salinity at Pooles Island (Continued)



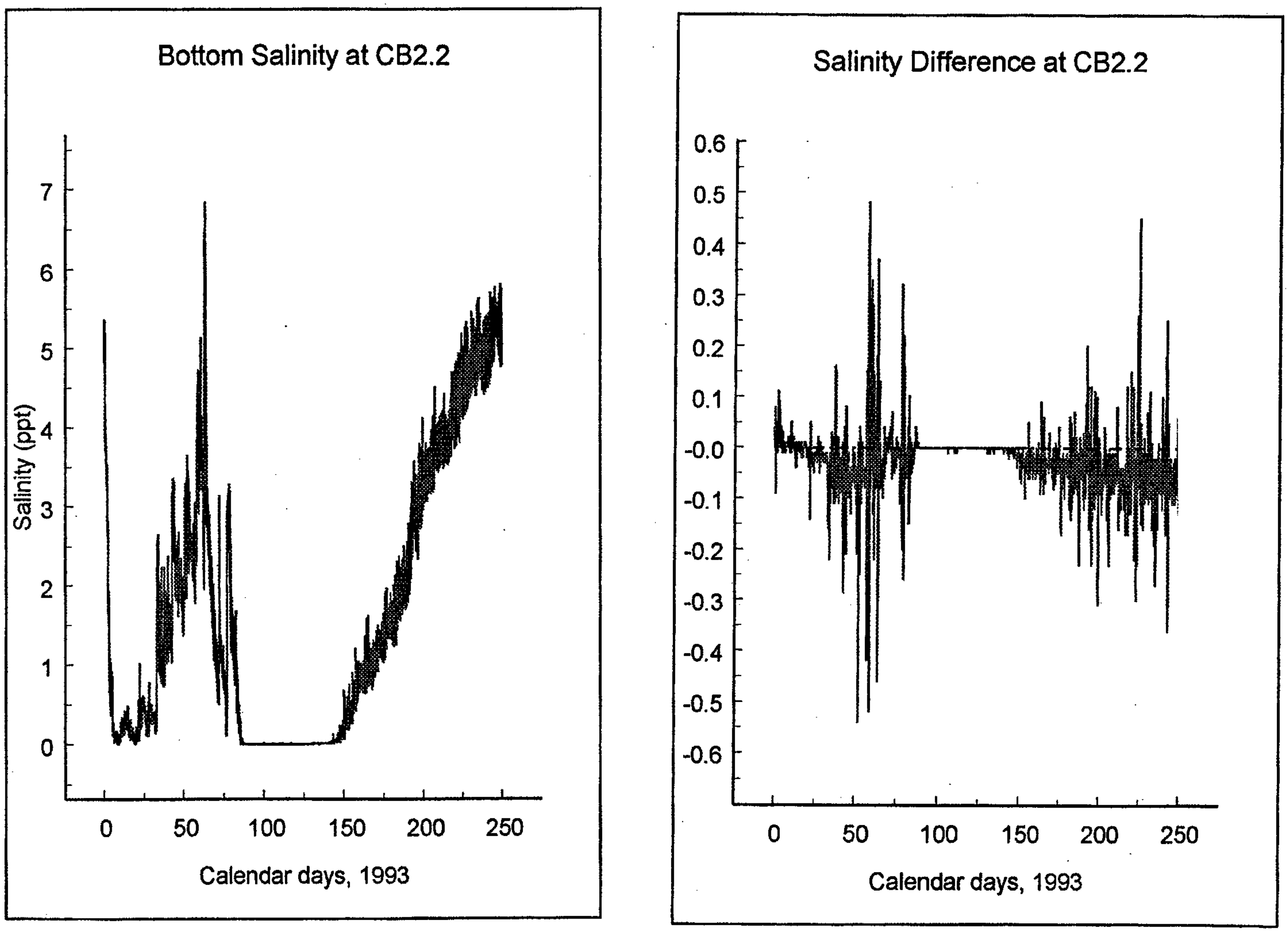
b. Bottom

Figure 93. (Concluded)



a. Surface

Figure 94. Impact on salinity at CB2.2 (Continued)



b. Bottom

Figure 94. (Concluded)

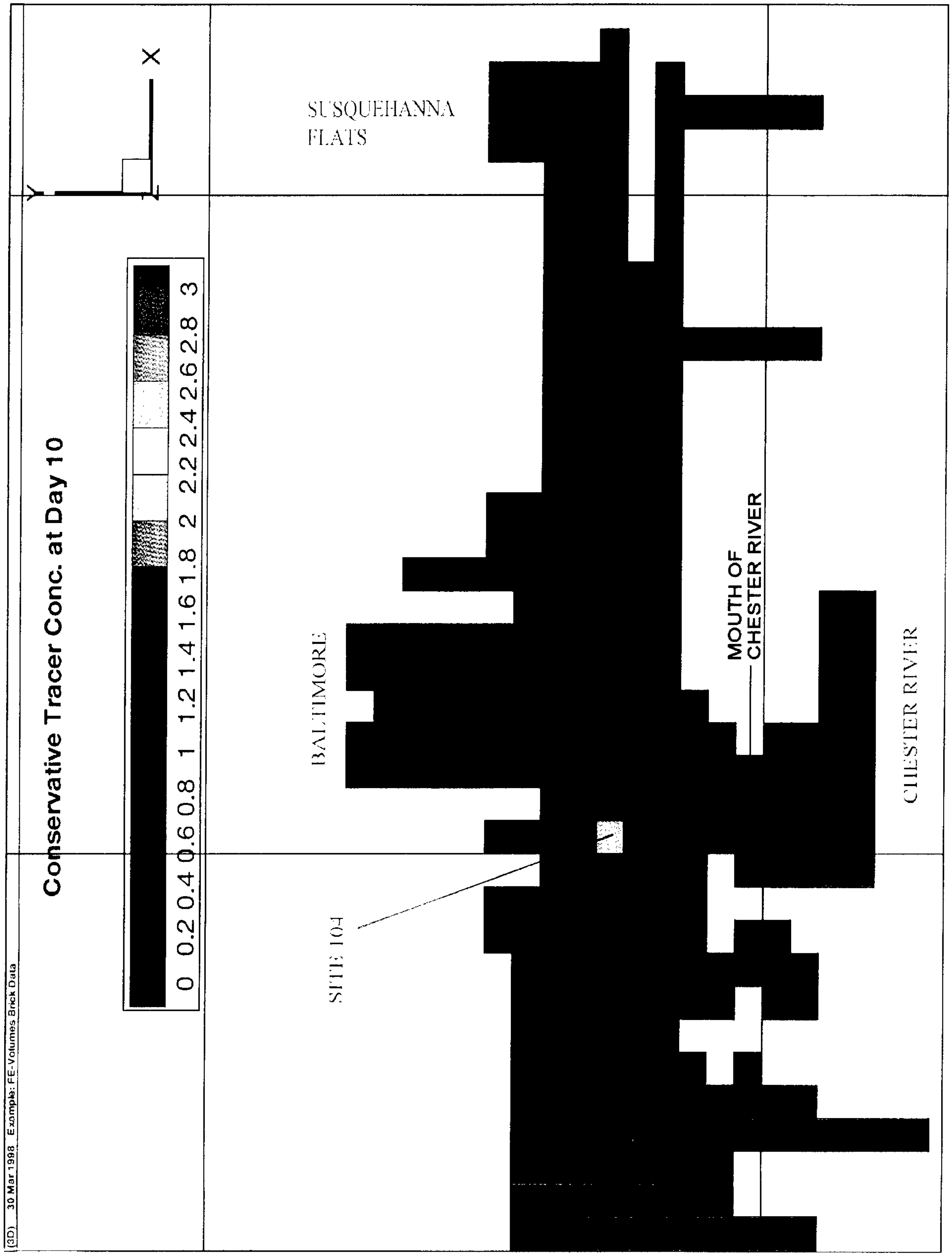


Figure 95. Conservative tracer concentration near bottom after 10 days

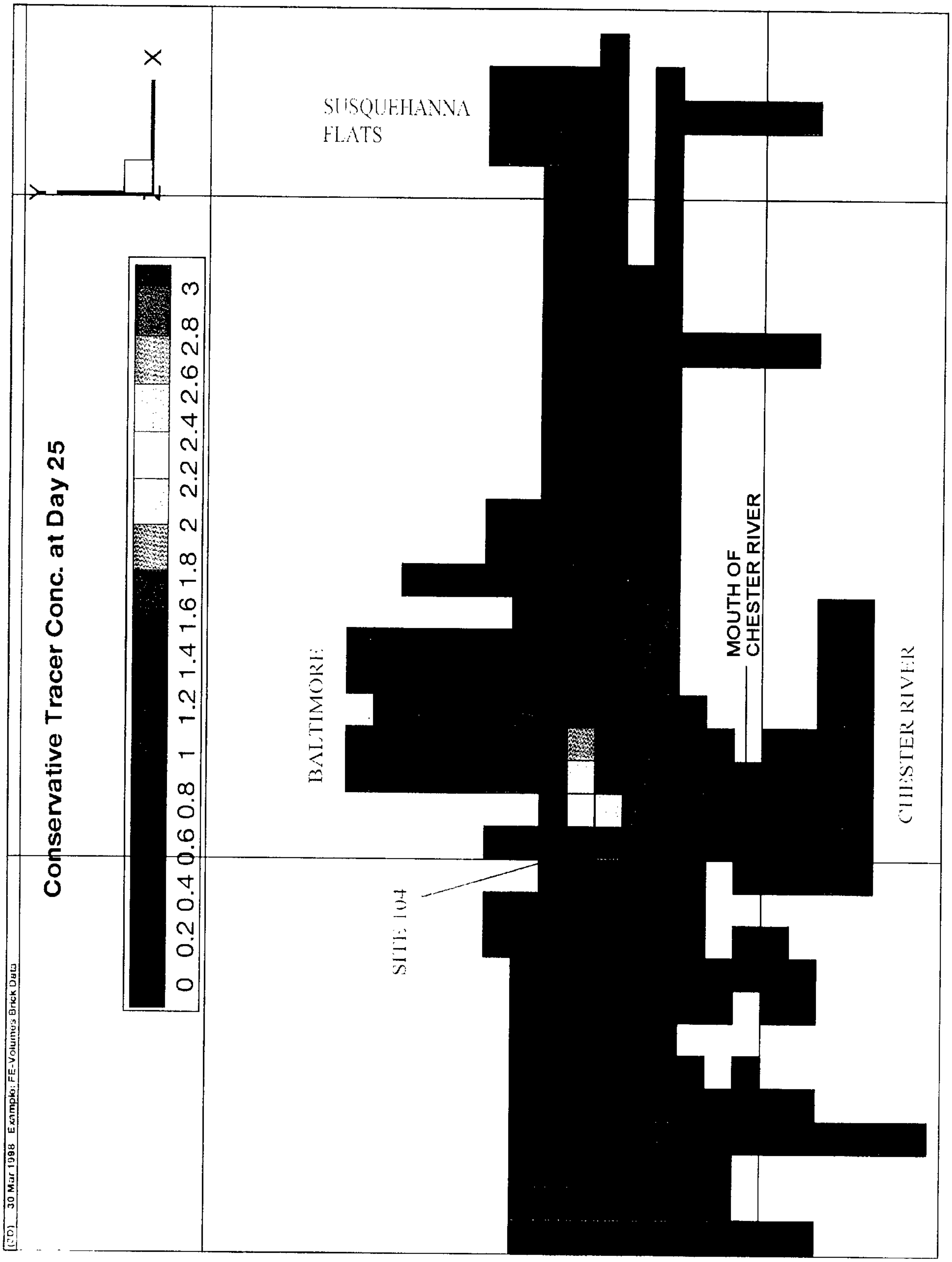


Figure 96. Conservative tracer concentration near bottom after 25 days

During this period, surface salinities over Site 104 were about 10-12 ppt with bottom salinities being approximately 15-17 ppt. The partial stratification of the water column results in the northward transport near the bottom (gravitational circulation) and also reduces vertical diffusion of nutrients released near the bottom. Since the waters of Chesapeake Bay normally experience turnover in late September, whereas dredging operations will occur during November - April, Site 104 waters will normally be partially stratified during dredged material placement.

The impact of this northward residual transport on placement material eroded from the site bottom is unclear. In one simulation, a settling velocity of 0.5 m/day, which is much smaller than typical settling velocities of fine-grained material, was assumed. Model results indicated virtually all tracer released would settle to the bottom without leaving the cell in which it was released. However, one should remember that this is not representative of sediment transport since suspended material does not settle until the shear stress falls below some critical value for deposition. All that can be said is that if suspended material or nutrients remain in suspension for long periods of time, some of the material or nutrients carried through the southern boundary of the site during ebb flow could possibly be carried back into the site during the next flood cycle, with the net drift being to the north.

As a final note, Cerco[1] has examined the water quality impact of dredging at a number of sites in Chesapeake Bay that were suggested by the Chesapeake Bay Program. Water quality impacts were similar to those determined at Site 104, i.e., essentially negligible. Consequently, the belief is that movement of nutrients away from Site 104 will not cause problems in other areas of Chesapeake Bay.

[1] Personal Communication, C. F. Cerco, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

12 Summary and Conclusions

Summary

Various numerical models have been applied to provide predictions of the potential loss of material placed at Site 104 and to assess the impact of material placement on the water quality at the site. The major limitation of the modeling effort is that questions concerning where material and/or nutrients that have the potential to leave Site 104 ultimately end up in Chesapeake Bay cannot be answered. To support the MDFATE sediment modeling, two series of erosion experiments were performed to assess the erodibility of placed material. The first tests were performed with a surficial sample of sediment from the Swan Point Channel. The second series of tests were for a composite sediment made up from samples collected from five of the channels proposed for dredged material placement at Site 104. In both cases, the erosion experiments were performed on sediments slurried at a 1:3 ratio (sediment to water) that had settled for several days. These experiments provided erosion information on newly deposited material as it recovered its field shear strength. In addition, erosion tests were also performed on the original channel sediment with no slurrying.

A 3-D hydrodynamic model (CH3D-WES) of the upper bay was applied using 1993 forcings to provide bottom-shear stresses and vertically averaged flows to the MDFATE model. Using results from the 3-D hydrodynamic model and results from the erosion tests, MDFATE was run with the Series II erosion parameters to simulate 5 years of material placement. The placement plan was constructed using a placement grid to maximize the site capacity while minimizing long-term erosion of placed dredged material. STFATE runs provided estimates of the amount of material loss as the material descends through the water column. SURGE runs provided estimates of the possible extent of the bottom surge created by the dredged material cloud striking the bottom. The full bay 3-D hydrodynamics and water quality models were used to address the impact on water quality of placing material in Site 104 and to demonstrate the impact of the bottom residual current on transport near the bottom of the site.

Conclusions

Using the erosion parameters developed from the Series II tests (Chapter 5, Erosion Tests) results in the computation of potentially moderate loss of solids placed at the site. Accounting for all sediment losses, MDFATE results indicate that about 17 percent of all solids placed at Site 104 by a scow or barge have the potential for leaving the site. Of this percentage, less than 1 percent is due to stripping of sediment during descent of the dredged material to the seafloor, with another 3.3 percent being due to material being transported from the site without ever being deposited. The above 4.3 percent material loss is due to short-term processes affecting dredged material during the placement operation. The remaining 12.6 percent potential material loss results from long-term erosion of deposited material because of bottom-shear stresses exceeding the critical shear stress determined from the Series II erosion tests.

Using the same erosion parameters and site hydrodynamics for hydraulic placement of the material, a total potential loss of 6.2 percent of the placed solids is computed. Since a basic assumption is that with this placement method there are no water column losses, all of the loss is due to erosion by the bottom currents. The hydraulic placement in this analysis was assumed to come from pump out of single barges. Such releases will be limited in time and of relatively small volume, resulting in individual footprints of limited extent compared with typical pipeline placement operations. Thus, the erosion for the hydraulic placement method is computed to be about half of that for the barge placement option.

The hydraulic (pump out) method of placement is predicted to produce a smaller footprint on the estuary bottom per placement than the scow or barge release method of placement. These differences are due to the following:

a. Hydraulic placement will result in material reaching the bottom at a higher concentration and thus with a lower total volume than a release from the bottom of a barge or scow.

b. Hydraulic placement results in a spreading layer that is of more limited vertical extent, viscous dominated, and laminar a short distance from the release point, while a barge bottom release is turbulent and continues to entrain as it spreads over the bottom.

c. Hydraulic placement results in a spreading layer that is closer to the bottom and less affected by ambient currents.

d. Hydraulic placement will result in a spreading layer that will increase in concentration and viscosity more rapidly than a barge release and will not spread as far from the release point as a barge release does.

The potential erosion (long-term) losses computed by MDFATE are dependent on the bottom-shear stresses computed by CH3D-WES. These are computed through a quadratic formulation based on the velocity computed

immediately above the bottom and a drag coefficient that has a value of about 0.0025. It should be noted that these shear stresses reflect the total drag (composed of both form drag and skin friction) experienced by the sea bottom. As discussed by Wright (1995), it is the skin friction shear stress, acting on a surface composed of sediment particles, that is responsible for sediment entrainment and transport. Using the Einstein-Barbarosa formulation as presented by Lyne, Butman, and Grant (1990) with an assumed grain-size roughness of 100 μm, one can show that an appropriate drag coefficient for calculating skin friction is about half the value used in CH3D-WES. Thus, it can be concluded that the bottom-shear stresses used in MDFATE for calculating erosion of the placed material are probably too high, resulting in elevated computed erosion rates.

A further substantiation that the erosion computed by MDFATE is on the high side can be inferred by the fact that MDFATE computes a net erosion of the existing material at Site 104 (Figure 55). As discussed in Chapter 9, this is contrary to the results reported by various researchers who have concluded that sedimentation rates in the deeper portions of Chesapeake Bay are generally higher than in surrounding waters. The deeper channels are relict features incised by the Susquehanna River and its tributaries during times of lower sea level, and they are now filling relatively rapidly with sediments (Colman, Halka, and Hobbs 1992). In the vicinity of Site 104, the long-term average rate of sedimentation accumulation (over 10,000 years) has been 3 mm/year (Colman and Halka 1990). Pollen-dating techniques applied to three recent sediment cores collected in the vicinity of Site 104 indicate that the rate of sediment accumulation since the time of European occupation has averaged approximately 4 mm/year (Brush 1990; Brush, Hill, and Unger 1997). Although these cores were not located within the site itself, and extrapolation of sedimentation rates from specific core locations is questionable, the results corroborate the long-term average. Higher sedimentation rates (10 to 30 mm/year) have been calculated from radio nuclide dating of two cores collected from the bottom of the deep-water area off Kent Island (Golberg et al. 1978).

Finally, one should note that some of the material that is carried through the southern boundary of the site either during the ebb part of the tidal cycle or as a density current will most likely be carried back into the site during the subsequent flood cycle. In addition, because of gravitational circulation, the residual current near the bottom of Site 104 is generally directed northward (Figures 95-96). Thus, material that remains in suspension near the bottom will experience long-term transport toward the northern end of the site. Therefore, given that the bottom-shear stresses used in MDFATE are likely too high, some eroded material may be redeposited within the site, and the bottom residual currents are to the north, one can conclude that the percentages of potential sediment loss presented here are conservative, and the actual loss will likely be less. In addition, one should remember that the northern boundary of Site 104 is considerably north of the MDFATE northern boundary. Therefore, some of the material leaving the northern boundary of the MDFATE grid may stay within the boundaries of Site 104.

Results from the water quality modeling indicate enhanced phosphorus concentrations in bottom waters at the site. The enhancement is a result of both elutriation during the placement and the subsequent release from bottom sediments following placement. Complete elutriation of sediment phosphorus may have a stimulatory effect on the spring algal bloom, but this stimulation has no long-term effects. During summer, elevated phosphorus concentrations are restricted to bottom waters far below the photic zone and have no influence on algae. Negligible impacts of the placement of dredged material were noted on dissolved oxygen. This is true at Site 104 as well as nearby locations, e.g., the mouth of the Chester River.

Conclusions can be summarized as follows:

a. Model results indicate a potential for a maximum of about 17 percent of dredged material released from the bottom of a barge or scow to leave the site. This includes potential loss of material during the placement operation as well as potential erosion of material after placement on the bottom.

b. Model results indicate a potential for about 6 percent of the material placed through a pipe close to the site bottom to leave the site.

c. Since the entire bottom-shear stress was used in computing erosion and since some material leaving the site could be carried back into the site, predicted sediment losses are considered conservative.

d. No quantitative information can be given on where the material ends up that leaves the site. However, the long-term movement of water over the site bottom is to the north.

e. Model results indicate a negligible impact on dissolved oxygen at Site 104 and at nearby locations because of the placement of 18 million cu yd of dredged material over 5 years at Site 104.

f. Assuming the Series II erosion results are representative of the dredged material proposed for placement in Site 104 and that the modified placement plan will be used, the site should be able to accomodate 18 million cu yd of placed material. However, some bottom dragging might be required to reduce the height of some placement mounds. Model results indicate that this would likely not be needed until after the fourth year of placement.

These model results should aid in assessing the impact of placing 18 million cu yd of dredged material at Site 104 over 5 years. Monitoring of the site is recommended to provide data to substantiate the model predictions under actual conditions.

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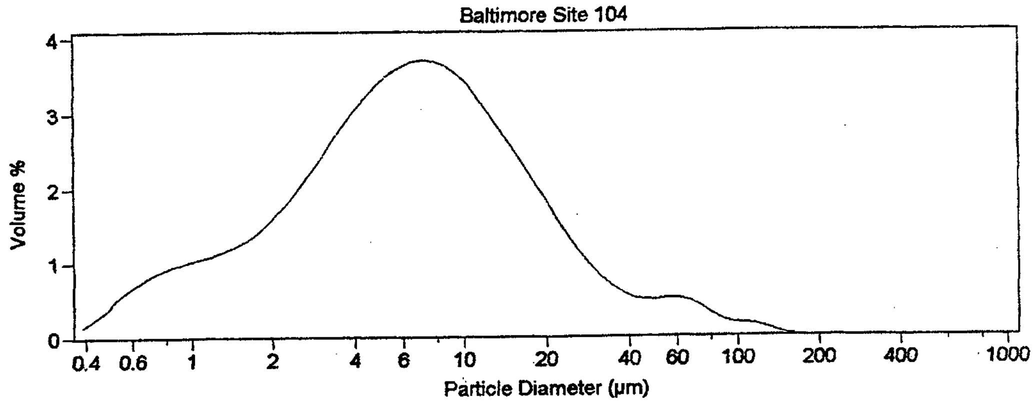
HYDRAULICS SEDIMENTATION LABORATORY

File name:	site104.$01	Group ID:	Site 104
Sample ID:	Baltimore Site 104		
Operator:	CRL	Run number:	1
Comments:	Brown clay, no or little sand. Calgon in chamber. Sample from bucket, homogenous mix, same as for PES.		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		



Volume Statistics (Arithmetic) site104.$01

Calculations from 0.375 μm to 948 μm

Volume	100.0%		
Mean:	10.92 μm	S.D.:	15.1 μm
Median:	6.370 μm	C.V.:	138%
D(3,2):	3.359 μm	Skewness:	3.86 Right skewed
Mode:	7.083 μm	Kurtosis:	19.5 Leptokurtic

% <	10	25	50	75	90
Size μm	1.333	3.066	6.370	12.38	22.92

site104.$01

Particle Diameter μm	Volume % <
4.000	32.94
15.60	81.83
44.00	96.02
74.00	98.68
125.0	99.85
250.0	100.00
500.0	100.00
1,000	100.00

Grain-size distribution for surficial grab sample from Swan Point

Plate 1

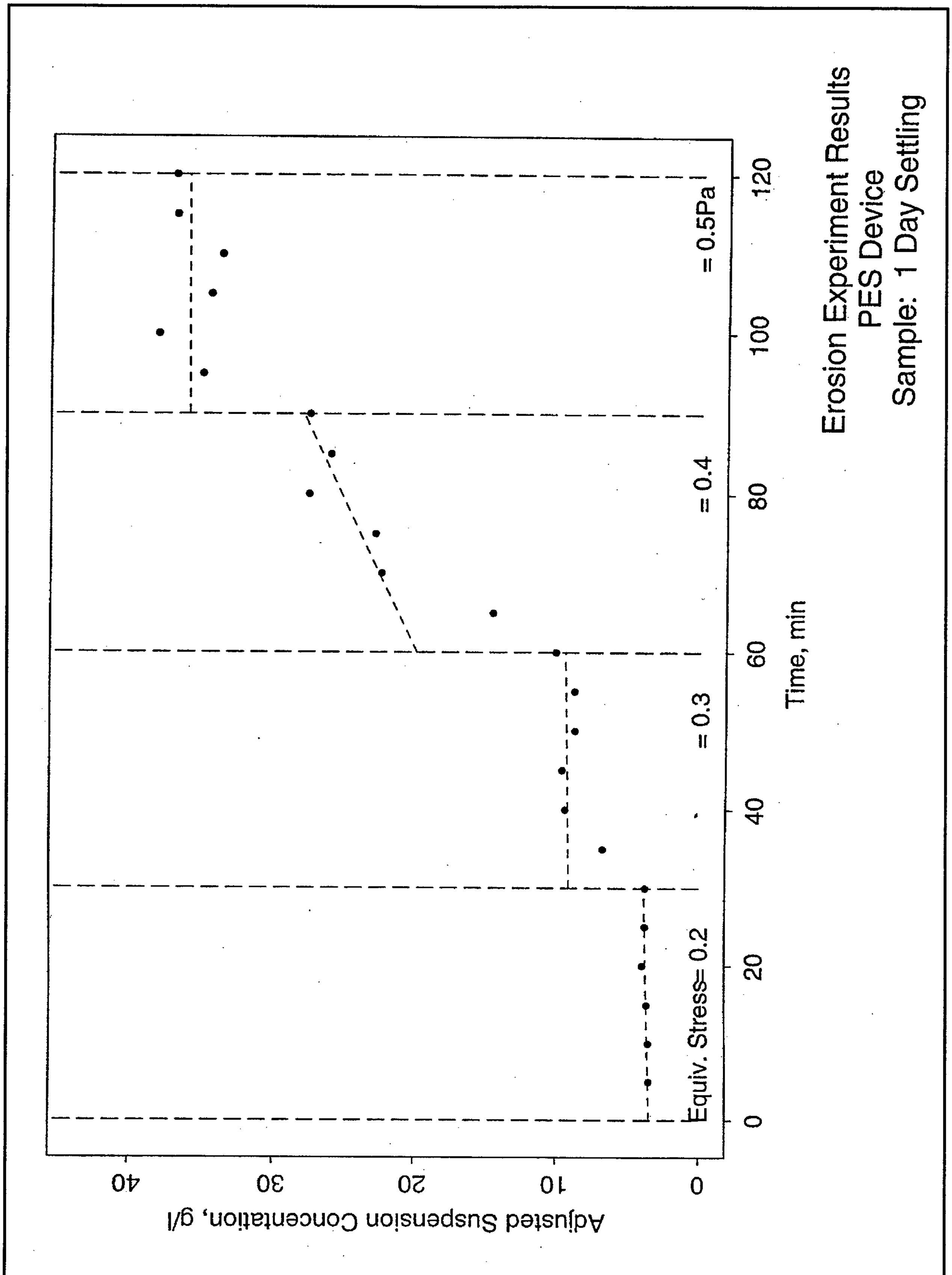

Erosion Experiment Results
PES Device
Sample: 1 Day Settling
Time, min
Adjusted Suspension Concentation, g/l
Equiv. Stress= 0.2
= 0.3
= 0.4
= 0.5Pa
0
20
40
60
80
100
120
0
10
20
30
40

Plate 2

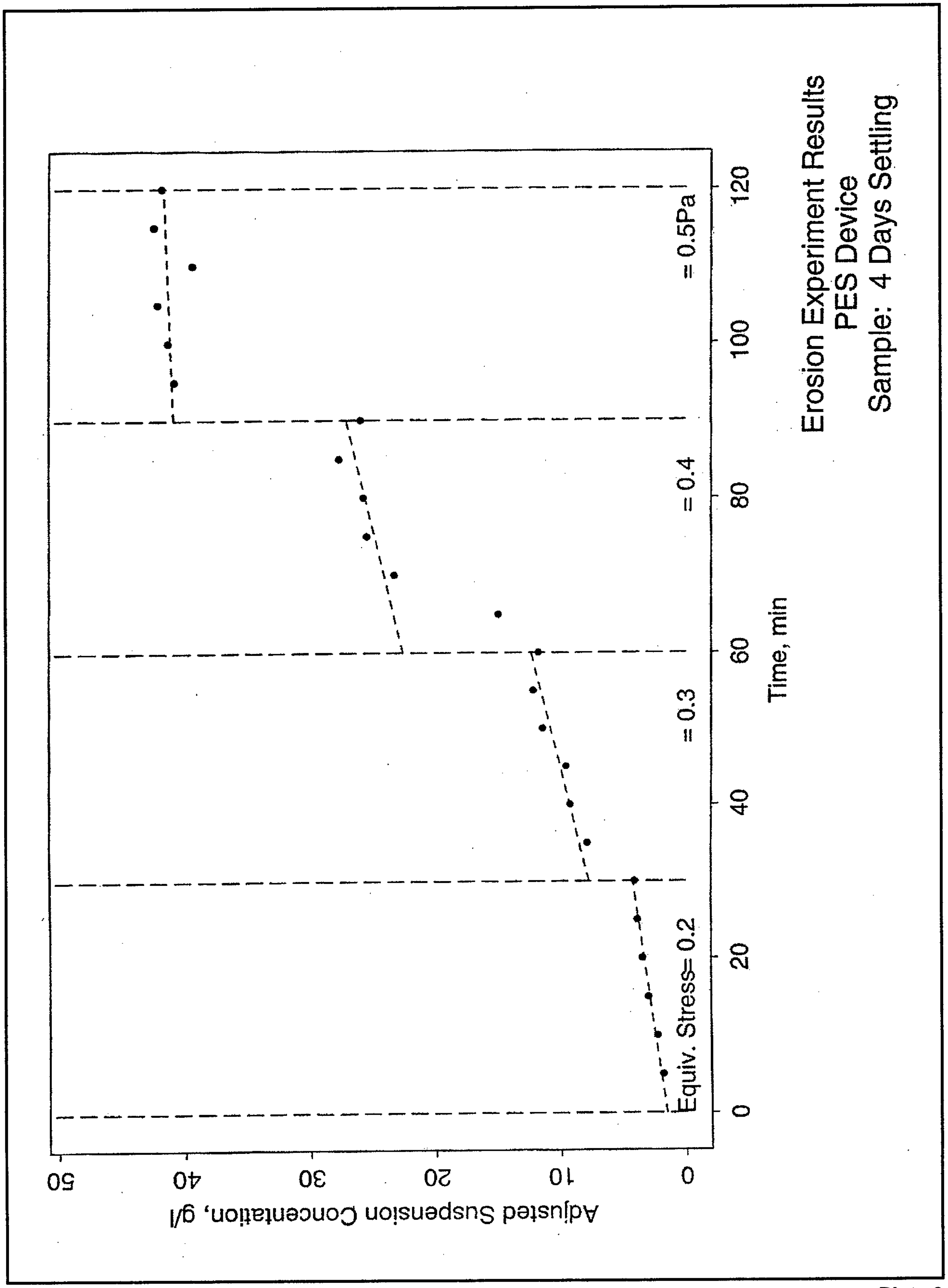

Erosion Experiment Results
PES Device
Sample: 4 Days Settling
Time, min
0
20
40
60
80
100
120
Adjusted Suspension Concentation, g/l
0
10
20
30
40
50
Equiv. Stress= 0.2
= 0.3
= 0.4
= 0.5Pa

Plate 3

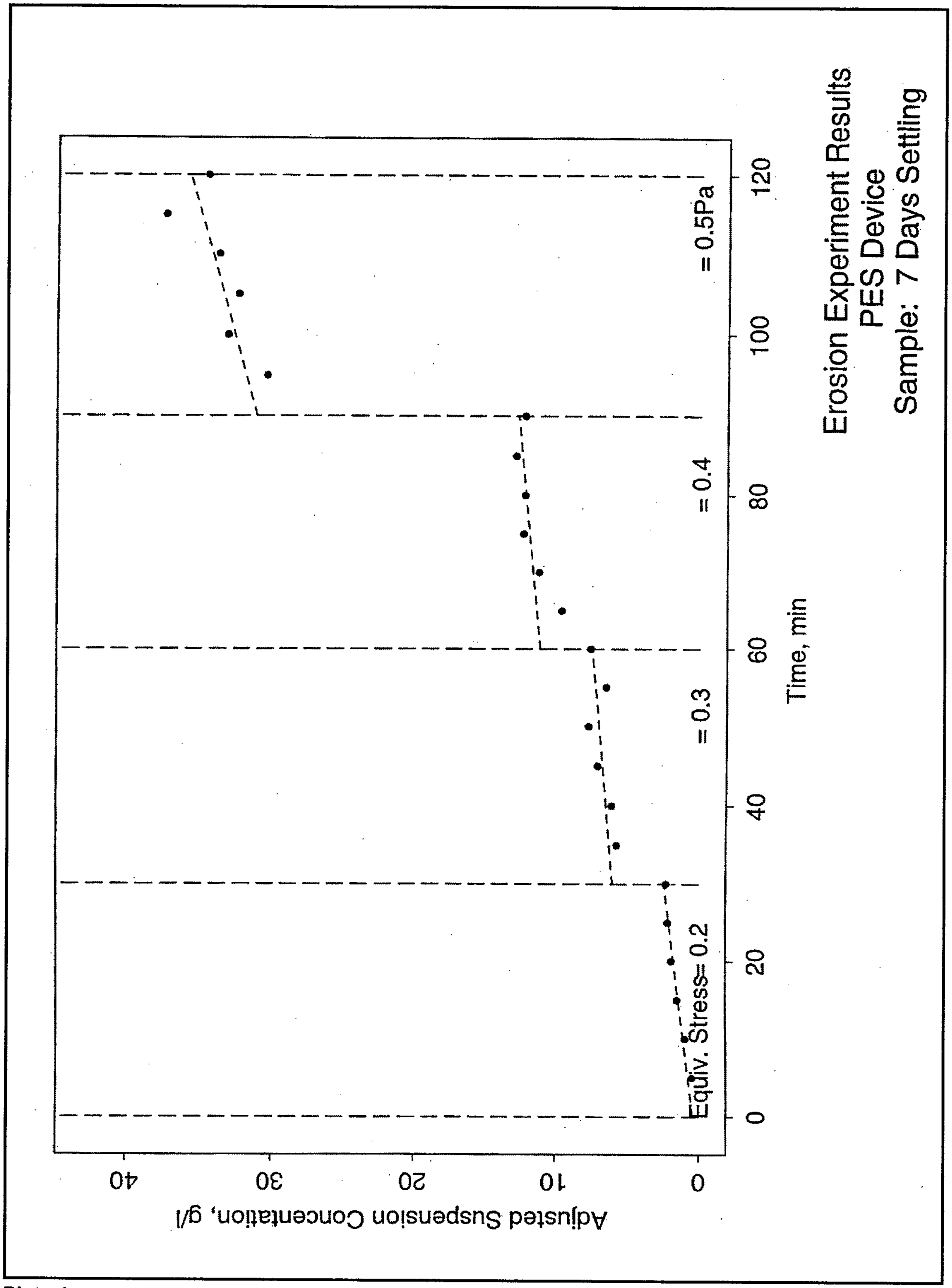
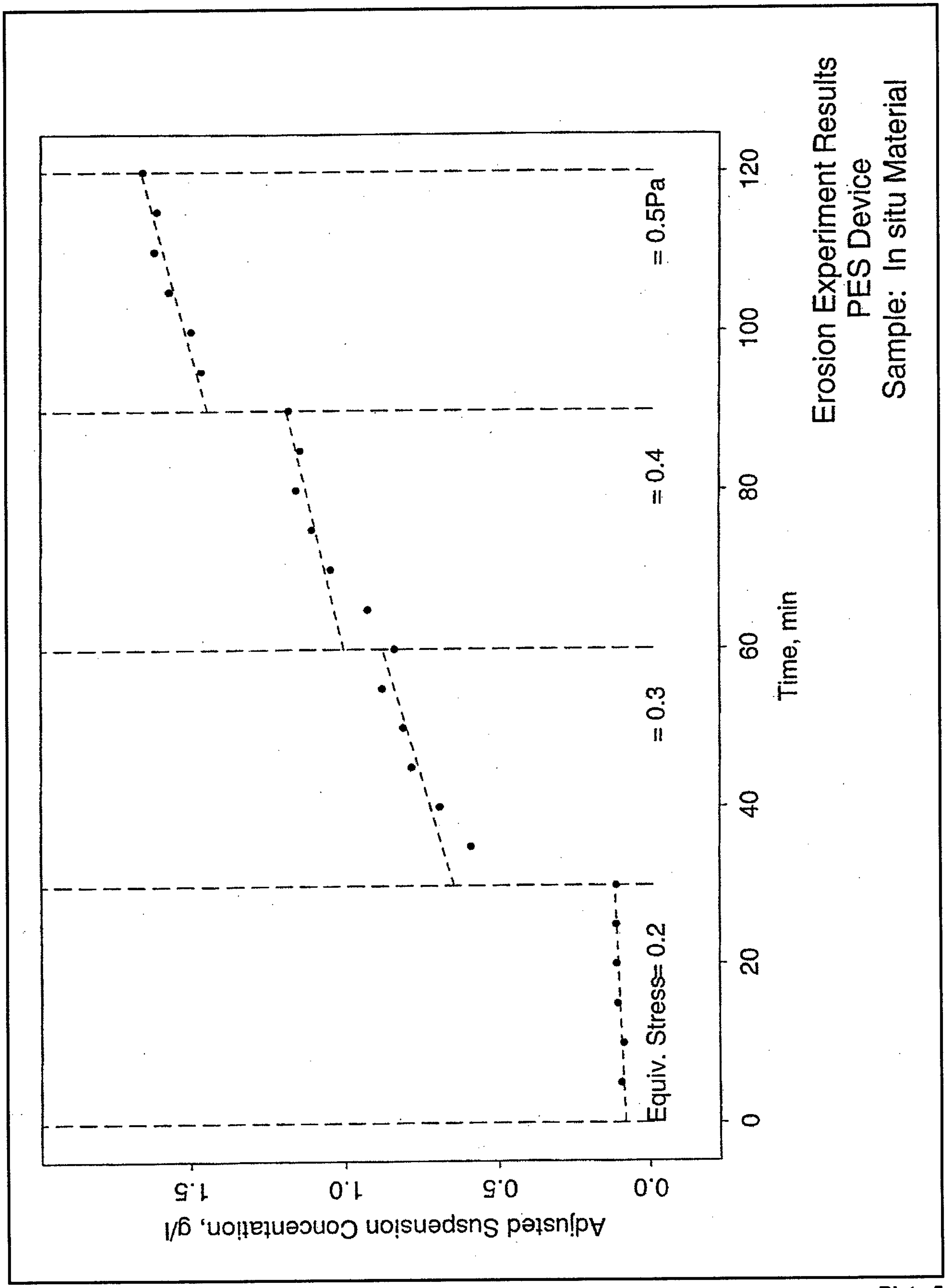
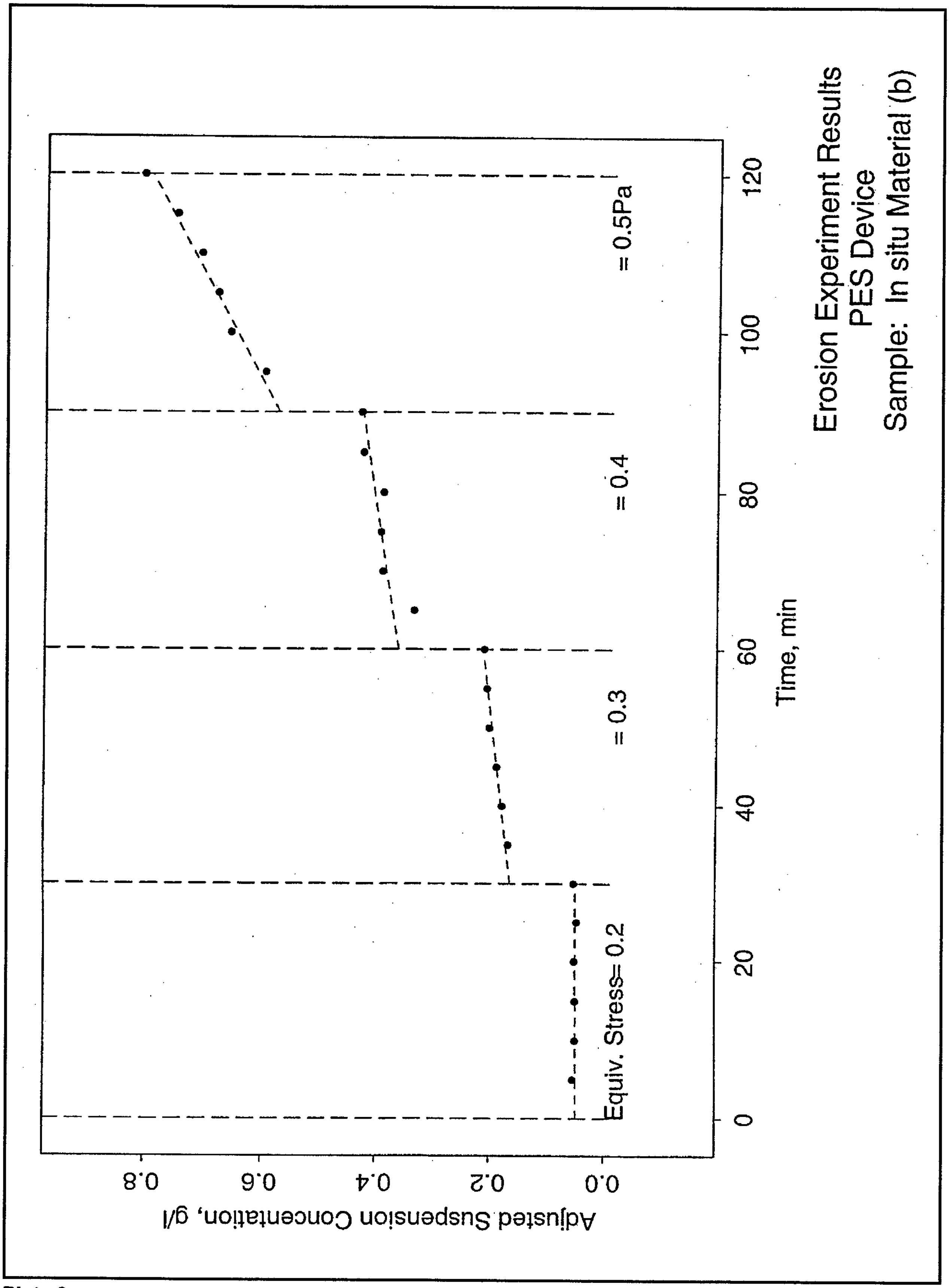

Erosion Experiment Results
PES Device
Sample: 7 Days Settling
Adjusted Suspension Concentration, g/l
Time, min
Equiv. Stress= 0.2
= 0.3
= 0.4
= 0.5Pa
0
10
20
30
40
0
20
40
60
80
100
120

Plate 4



Erosion Experiment Results
PES Device
Sample: In situ Material
Adjusted Suspension Concentation, g/l
0.0
0.5
1.0
1.5
Time, min
0
20
40
60
80
100
120
Equiv. Stress= 0.2
= 0.3
= 0.4
= 0.5Pa

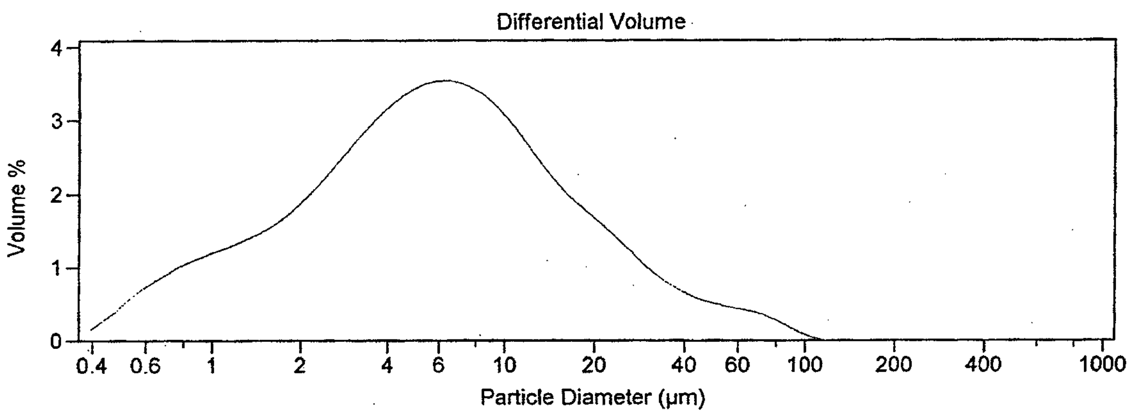
Plate 5



Erosion Experiment Results
PES Device
Sample: In situ Material (b)
Equiv. Stress= 0.2
= 0.3
= 0.4
= 0.5Pa
Time, min
0
20
40
60
80
100
120
Adjusted Suspension Concentation, g/l
0.0
0.2
0.4
0.6
0.8

Plate 6

File name:	upperms.$12	Group ID:	upperms
Sample ID:	Site 104 no. 6		
Operator:	vaughan	Run number:	13
Comments:	Site 104 no 1-Craighill Angle organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	12:23 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	9%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$12

Calculations from 0.375 μm to 948 μm

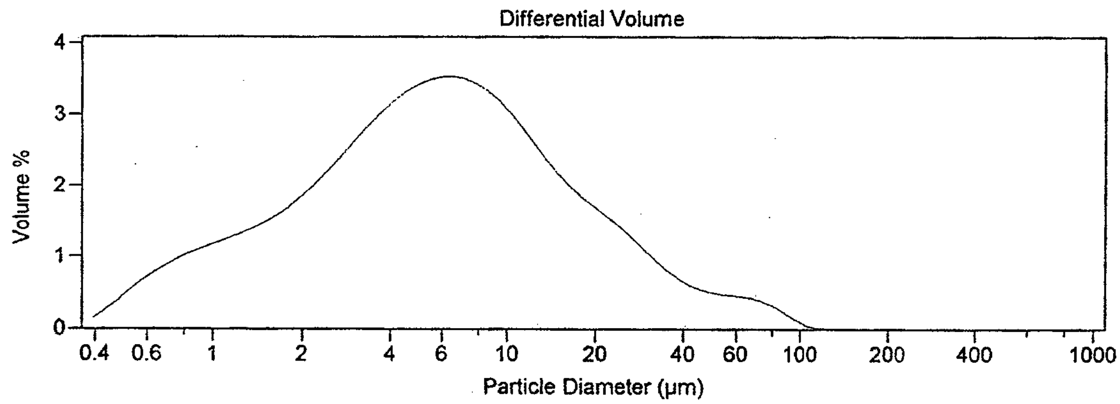
Volume	100.0%		
Mean:	9.954 μm	S.D.:	12.9 μm
Median:	5.710 μm	C.V.:	129%
D(3,2):	3.086 μm	Skewness:	3.14 Right skewed
Mode:	6.452 μm	Kurtosis:	12.4 Leptokurtic

% <	10	25	50	75	90
Size μm	1.206	2.670	5.710	11.55	22.90

Grain-size distribution for Core 1, Craighill Angle

Plate 7

File name:	upperms.$13	Group ID:	upperms
Sample ID:	Site 104 no. 6		
Operator:	vaughan	Run number:	14
Comments:	Site 104 no 1-Craighill Angle organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	12:39 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	9%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$13

Calculations from 0.375 µm to 948 µm

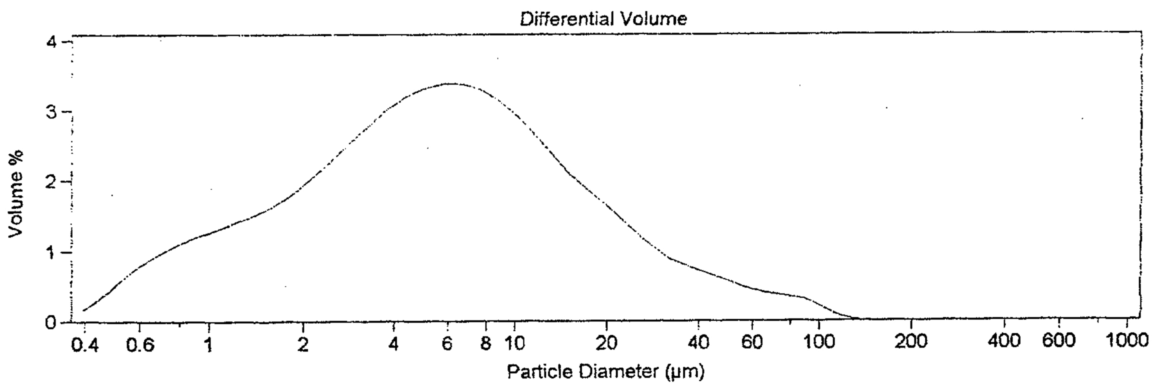
Volume	100.0%		
Mean:	10.15 µm	S.D.:	13.2 µm
Median:	5.781 µm	C.V.:	130%
D(3,2):	3.119 µm	Skewness:	3.14 Right skewed
Mode:	6.452 µm	Kurtosis:	12.4 Leptokurtic

% <	10	25	50	75	90
Size µm	1.221	2.703	5.781	11.72	23.49

Grain-size distribution for Core 1, Craighill Angle - duplicate test

Plate 8

File name:	UPPERMS.$14	Group ID:	upperms
Sample ID:	Site 104 no. 7		
Operator:	vaughan	Run number:	15
Comments:	Site 104 no 2-Cut off Angle organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	13:33 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	10%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$14

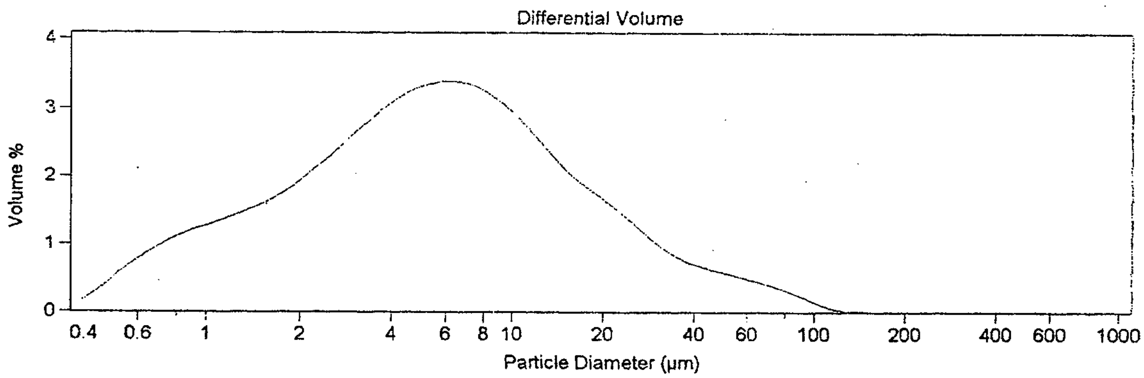
Calculations from 0.375 μm to 948 μm

Volume	100.0%		
Mean:	10.44 μm	S.D.:	14.5 μm
Median:	5.604 μm	C.V.:	139%
D(3,2):	2.993 μm	Skewness:	3.34 Right skewed
Mode:	5.878 μm	Kurtosis:	13.8 Leptokurtic

% <	10	25	50	75	90
Size μm	1.149	2.543	5.604	11.73	24.12

Grain-size distribution for Core 2, Cutoff Angle

File name:	UPPERMS.$15	Group ID:	upperms
Sample ID:	Site 104 no. 7		
Operator:	vaughan	Run number:	16
Comments:	Site 104 no 2-Cut off Angle organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	13:43 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	9%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$15

Calculations from 0.375 µm to 948 µm

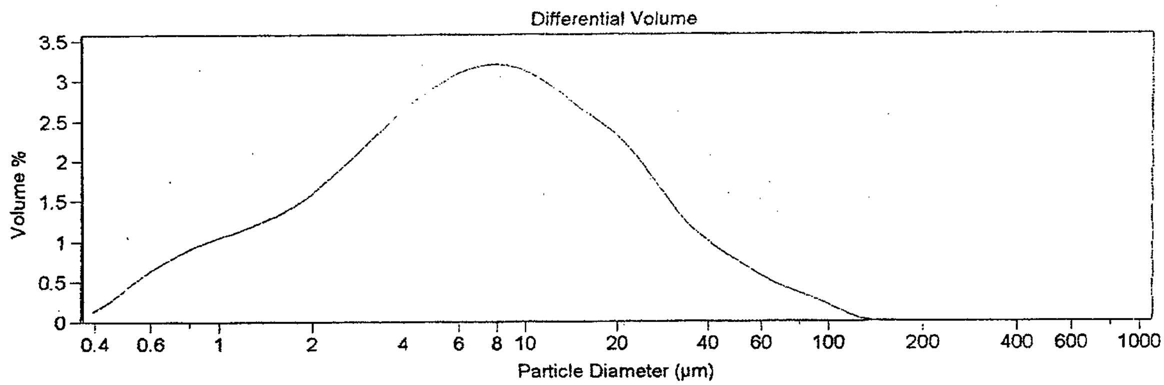
Volume	100.0%		
Mean:	10.27 µm	S.D.:	13.9 µm
Median:	5.610 µm	C.V.:	135%
D(3,2):	2.998 µm	Skewness:	3.23 Right skewed
Mode:	5.878 µm	Kurtosis:	13.1 Leptokurtic

% <	10	25	50	75	90
Size µm	1.153	2.545	5.610	11.71	23.88

Grain-size distribution for Core 2, Cutoff Angle - duplicate test

Plate 10

File name:	UPPERMS.$16	Group ID:	upperms
Sample ID:	Site 104 no. 8		
Operator:	vaughan	Run number:	17
Comments:	Site 104 no 3+4 - Brewerton E. Ext organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	13:52 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	10%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$16

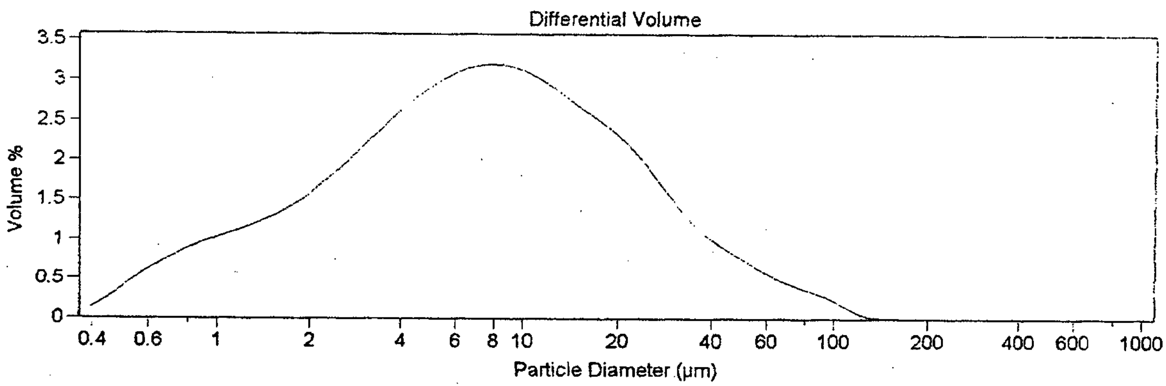
Calculations from 0.375 μm to 948 μm

Volume	100.0%		
Mean:	12.39 μm	S.D.:	15.4 μm
Median:	7.093 μm	C.V.:	124%
D(3,2):	3.476 μm	Skewness:	2.86 Right skewed
Mode:	7.776 μm	Kurtosis:	10.6 Leptokurtic

% <	10	25	50	75	90
Size μm	1.328	3.093	7.093	15.33	29.16

Grain-size distribution for Core 3 and 4, Brewerton Extension

File name:	UPPERMS.$17	Group ID:	upperms
Sample ID:	Site 104 no. 8		
Operator:	vaughan	Run number:	18
Comments:	Site 104 no 3+4 - Brewerton E. Ext organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	14:00 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	9%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$17

Calculations from 0.375 µm to 948 µm

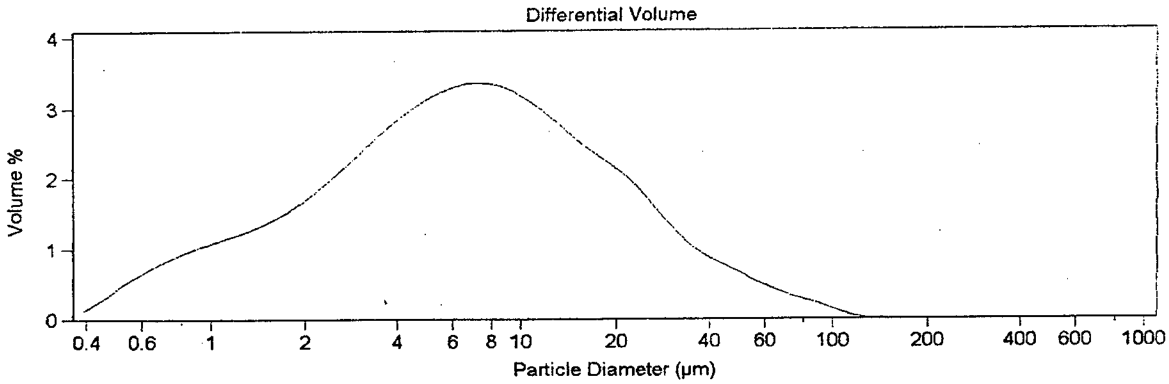
Volume	100.0%		
Mean:	12.51 µm	S.D.:	15.5 µm
Median:	7.163 µm	C.V.:	124%
D(3,2):	3.509 µm	Skewness:	2.83 Right skewed
Mode:	7.776 µm	Kurtosis:	10.3 Leptokurtic

% <	10	25	50	75	90
Size µm	1.344	3.126	7.163	15.46	29.44

Grain-size distribution for Core 3 and 4, Brewerton Extension - duplicate test

Plate 12

File name:	UPPERMS.$18	Group ID:	upperms
Sample ID:	Site 104 no. 9		
Operator:	vaughan	Run number:	19
Comments:	Site 104 no 5 - Tolchester organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	14:08 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	10%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$18

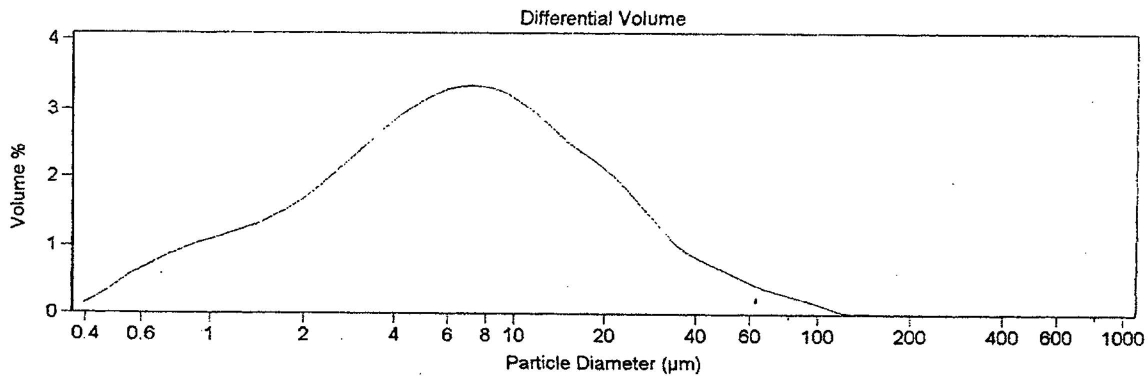
Calculations from 0.375 µm to 948 µm

Volume	100.0%		
Mean:	11.27 µm	S.D.:	13.9 µm
Median:	6.578 µm	C.V.:	123%
D(3,2):	3.364 µm	Skewness:	2.94 Right skewed
Mode:	7.083 µm	Kurtosis:	11.5 Leptokurtic

% <	10	25	50	75	90
Size µm	1.305	2.964	6.578	13.84	26.29

Grain-size distribution for Core 5, Tolchester Channel

File name:	UPPERMS.$19	Group ID:	upperms
Sample ID:	Site 104 no. 9		
Operator:	vaughan	Run number:	20
Comments:	Site 104 no 5 - Tolchester organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module,		
Start time:	14:16 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	10%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$19

Calculations from 0.375 μm to 948 μm

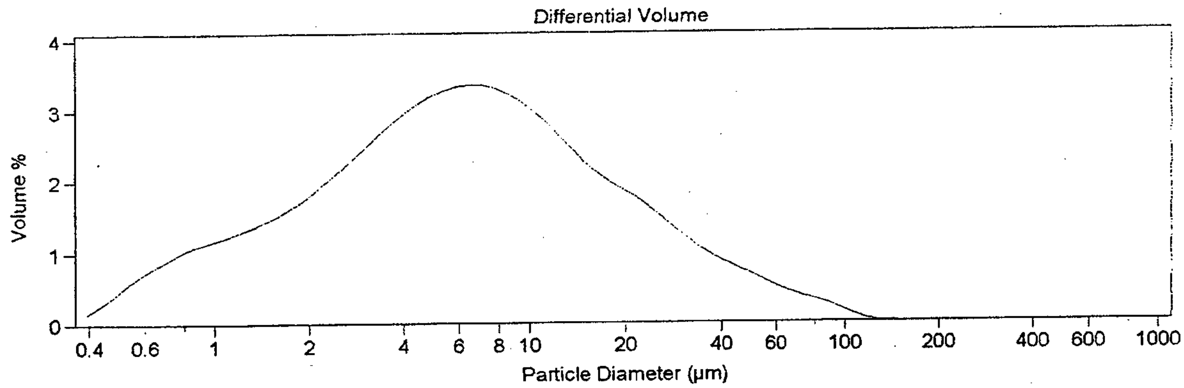
Volume	100.0%		
Mean:	11.22 μm	S.D.:	13.9 μm
Median:	6.545 μm	C.V.:	124%
D(3,2):	3.347 μm	Skewness:	2.98 Right skewed
Mode:	7.083 μm	Kurtosis:	11.8 Leptokurtic

% <	10	25	50	75	90
Size μm	1.296	2.948	6.545	13.75	26.09

Grain-size distribution for Core 5, Tolchester Channel - Duplicate Test

Plate 14

File name:	UPPERMS.$20	Group ID:	upperms
Sample ID:	Site 104 no. 10		
Operator:	vaughan	Run number:	21
Comments:	Site 104 no 6a+6b - Swan Point organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	14:24 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	10%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$20

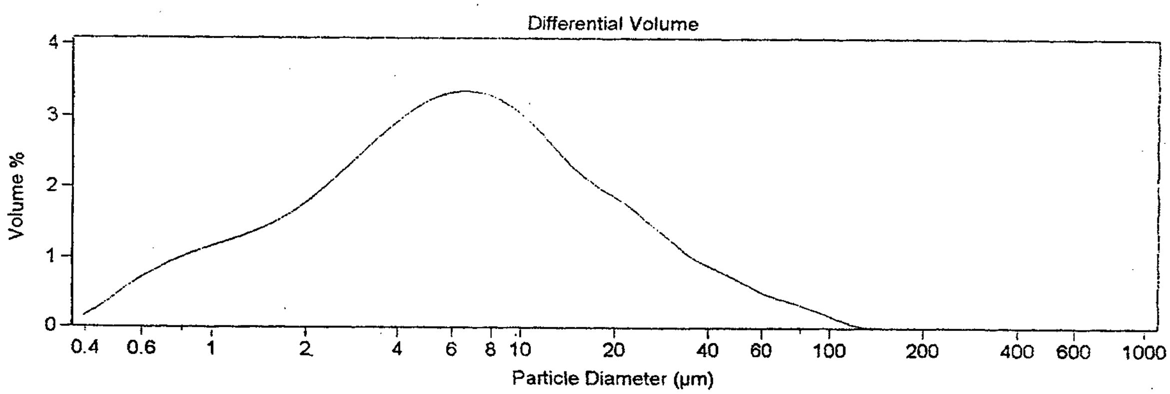
Calculations from 0.375 μm to 948 μm

Volume	100.0%		
Mean:	11.07 μm	S.D.:	14.4 μm
Median:	6.108 μm	C.V.:	130%
D(3,2):	3.182 μm	Skewness:	2.98 Right skewed
Mode:	6.452 μm	Kurtosis:	11.3 Leptokurtic

% <	10	25	50	75	90
Size μm	1.222	2.754	6.108	12.97	26.58

Grain-size distribution for Core 6, Swan Point

File name:	UPPERMS.$21	Group ID:	upperms
Sample ID:	Site 104 no. 10		
Operator:	vaughan	Run number:	22
Comments:	Site 104 no 6a+6b - Swan Point organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	14:31 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	9%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.S21

Calculations from 0.375 µm to 948 µm

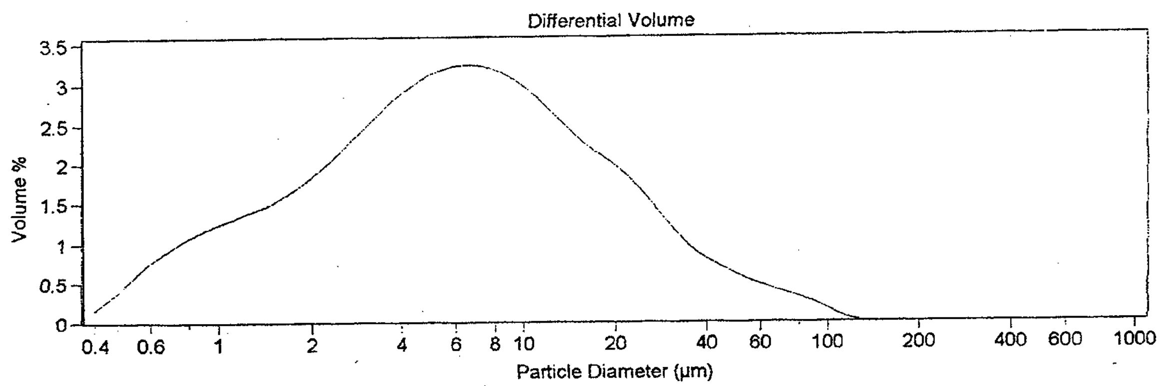
Volume	100.0%		
Mean:	11.12 µm	S.D.:	14.4 µm
Median:	6.131 µm	C.V.:	130%
D(3,2):	3.194 µm	Skewness:	2.98 Right skewed
Mode:	6.452 µm	Kurtosis:	11.3 Leptokurtic

% <	10	25	50	75	90
Size µm	1.228	2.766	6.131	13.04	26.67

Grain-size distribution for Core 6, Swan Point - duplicate test

Plate 16

File name:	UPPERMS.$22	Group ID:	upperms
Sample ID:	Site 104 no. 11		
Operator:	vaughan	Run number:	23
Comments:	Site 104 original - composite of 104 samples organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	14:40 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	10%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$22

Calculations from 0.375 μm to 948 μm

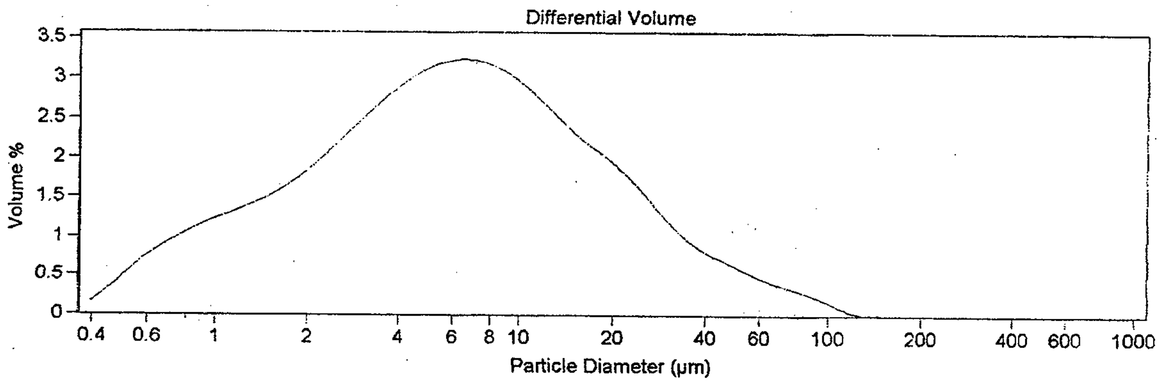
Volume	100.0%		
Mean:	10.93 μm	S.D.:	14.2 μm
Median:	6.033 μm	C.V.:	130%
D(3,2):	3.103 μm	Skewness:	3.05 Right skewed
Mode:	6.452 μm	Kurtosis:	11.9 Leptokurtic

% <	10	25	50	75	90
Size μm	1.177	2.652	6.033	13.05	25.80

Grain-size distribution for the channel reach composite

Plate 17

File name:	UPPERMS.$23	Group ID:	upperms
Sample ID:	Site 104 no. 11		
Operator:	vaughan	Run number:	24
Comments:	Site 104 original - composite of 104 samples organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	14:50 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	10%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$23

Calculations from 0.375 µm to 948 µm

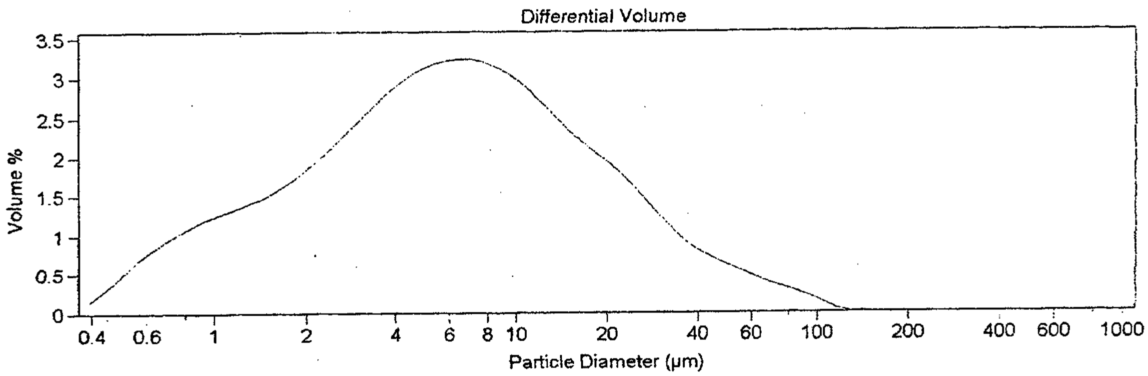
Volume	100.0%		
Mean:	10.90 µm	S.D.:	14.2 µm
Median:	6.011 µm	C.V.:	130%
D(3,2):	3.099 µm	Skewness:	3.05 Right skewed
Mode:	6.452 µm	Kurtosis:	11.9 Leptokurtic

% <	10	25	50	75	90
Size µm	1.177	2.643	6.011	12.99	25.76

Grain-size distribution for the channel reach composite - duplicate test 1

Plate 18

File name:	UPPERMS.$24	Group ID:	upperms
Sample ID:	Site 104 no. 11		
Operator:	vaughan	Run number:	25
Comments:	Site 104 original - composite of 104 samples organics removed calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	15:02 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	9%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$24

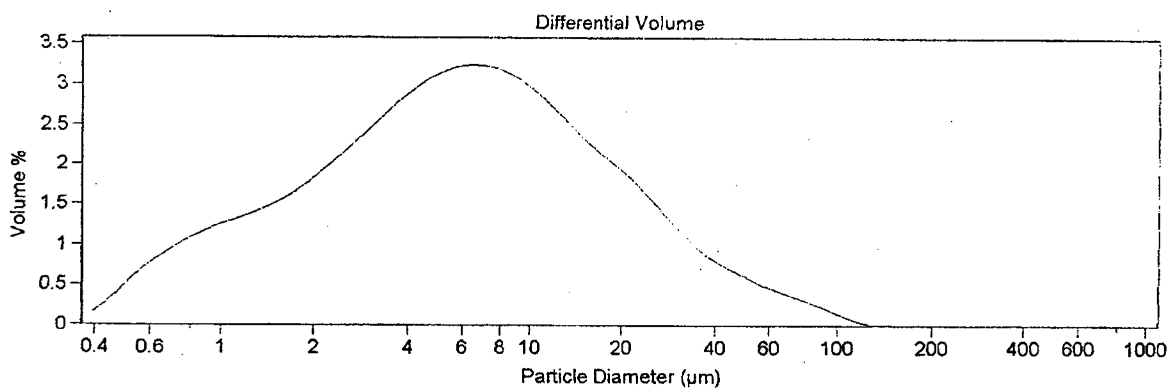
Calculations from 0.375 µm to 948 µm

Volume	100.0%		
Mean:	10.89 µm	S.D.:	14.2 µm
Median:	6.034 µm	C.V.:	130%
D(3,2):	3.105 µm	Skewness:	3.06 Right skewed
Mode:	6.452 µm	Kurtosis:	12.1 Leptokurtic

% <	10	25	50	75	90
Size µm	1.179	2.655	6.034	13.00	25.75

Grain-size distribution for the channel reach composite - duplicate test 2

File name:	UPPERMS.$25	Group ID:	upperms
Sample ID:	Site 104 no. 11		
Operator:	vaughan	Run number:	26
Comments:	Site 104 original - composite of 104 samples organics removed, calgon added		
Optical model:	Fraunhofer		
LS 100Q	Fluid Module		
Start time:	15:04 17 Feb 1998	Run length:	60 Seconds
Pump speed:	67		
Obscuration:	9%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02



Volume Statistics (Arithmetic) upperms.$25

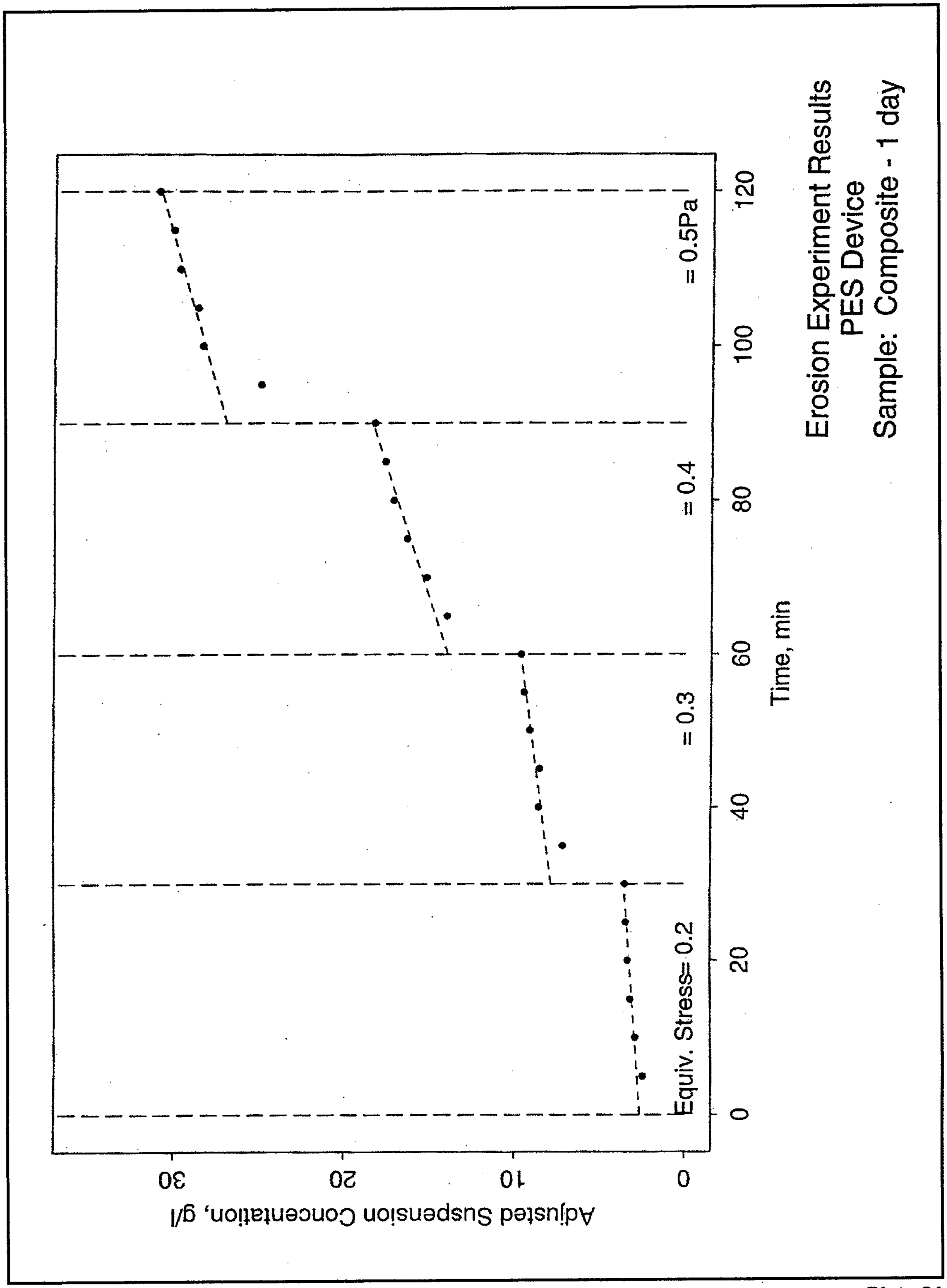
Calculations from 0.375 µm to 948 µm

Volume	100.0%		
Mean:	10.79 µm	S.D.:	14 µm
Median:	6.005 µm	C.V.:	129%
D(3,2):	3.082 µm	Skewness:	3.04 Right skewed
Mode:	6.452 µm	Kurtosis:	12 Leptokurtic

% <	10	25	50	75	90
Size µm	1.166	2.637	6.005	12.92	25.50

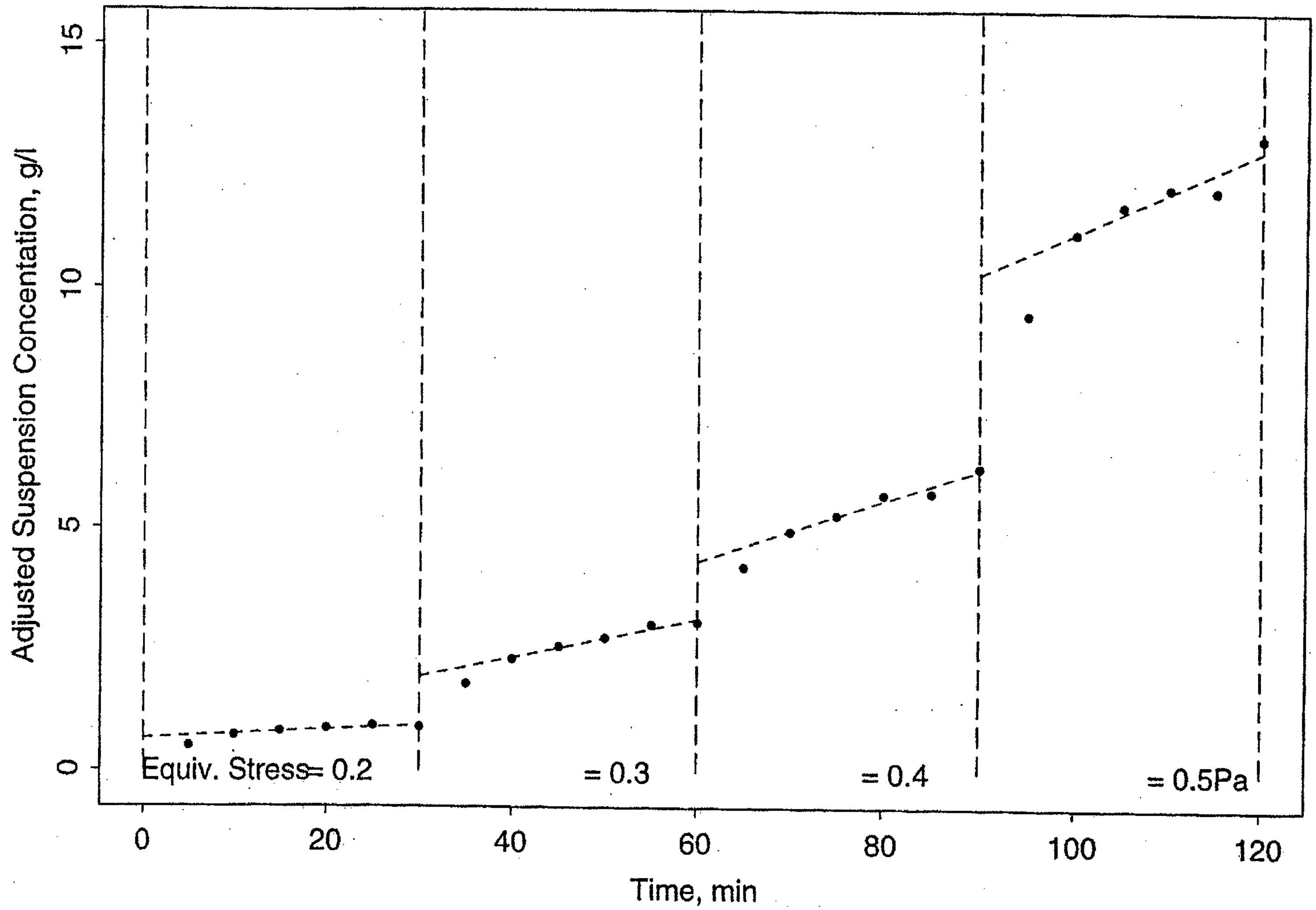
Grain-size distribution for the channel reach composite - duplicate test 3

Plate 20



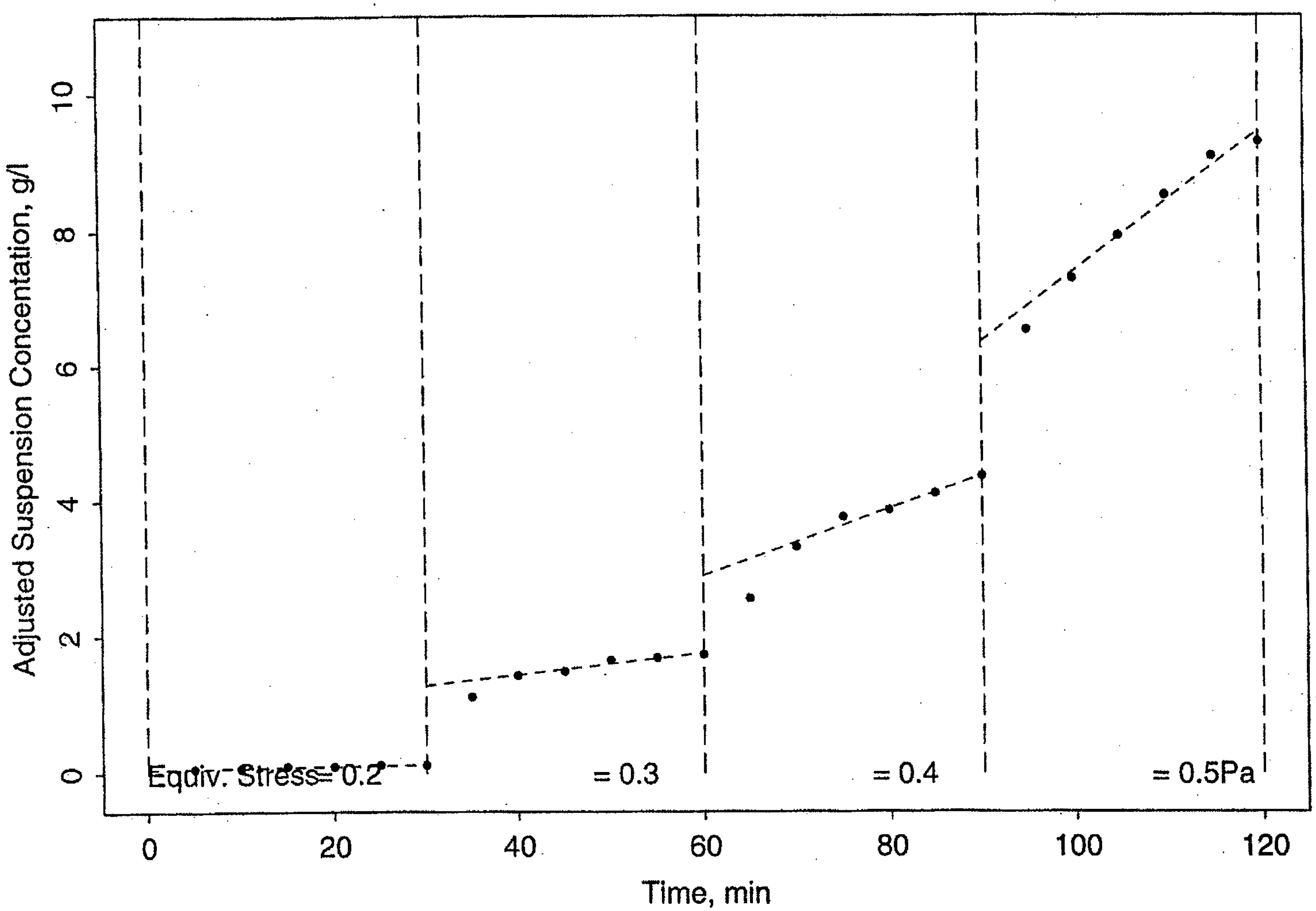
Erosion Experiment Results
PES Device
Sample: Composite - 1 day
Adjusted Suspension Concentration, g/l
Time, min
0
10
20
30
0
20
40
60
80
100
120
Equiv. Stress= 0.2
= 0.3
= 0.4
= 0.5Pa

Plate 21



Erosion Experiment Results
PES Device
Sample: Composite - 2 days

Plate 22



Erosion Experiment Results
PES Device
Sample: Composite - 4 days

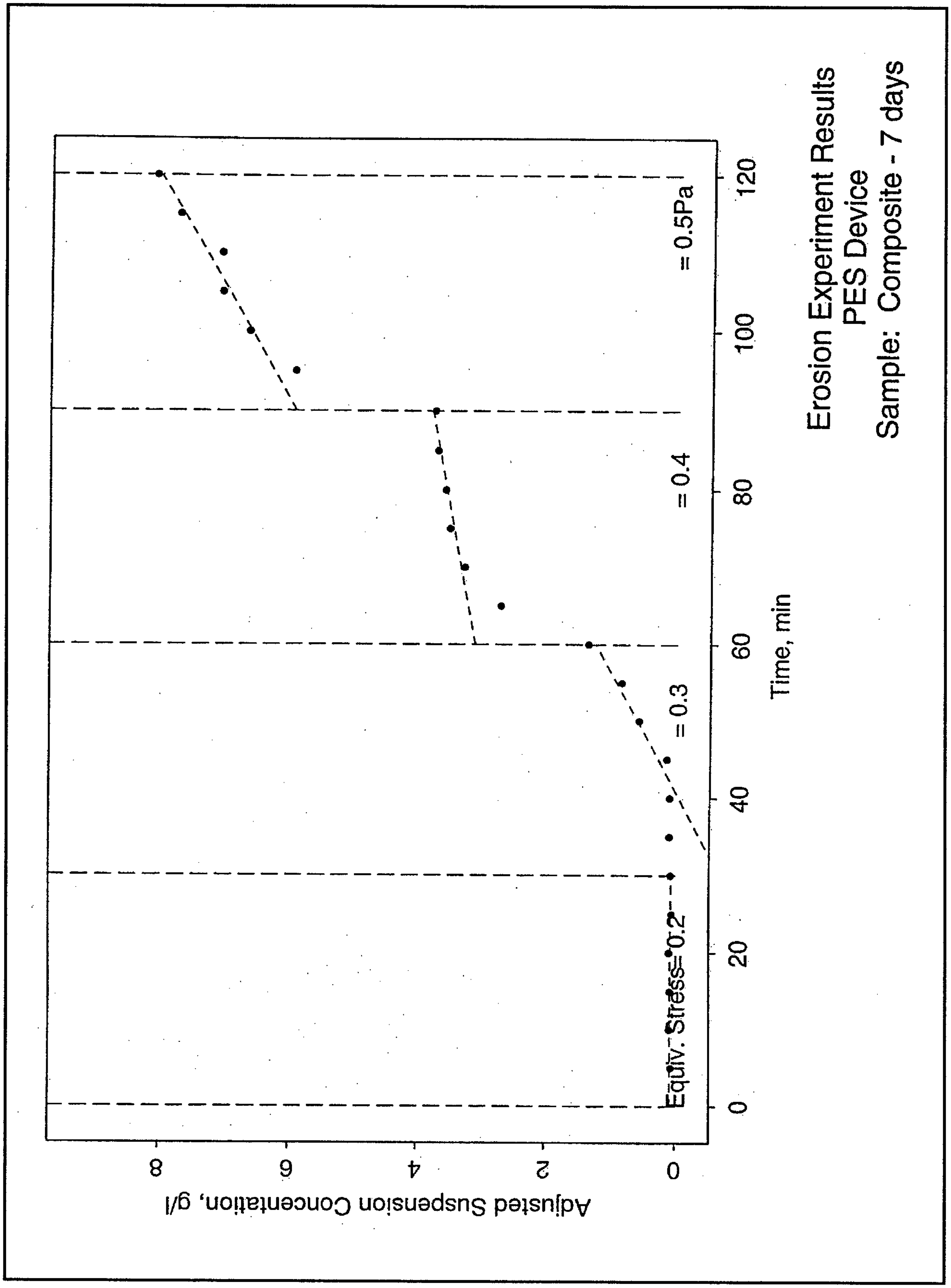
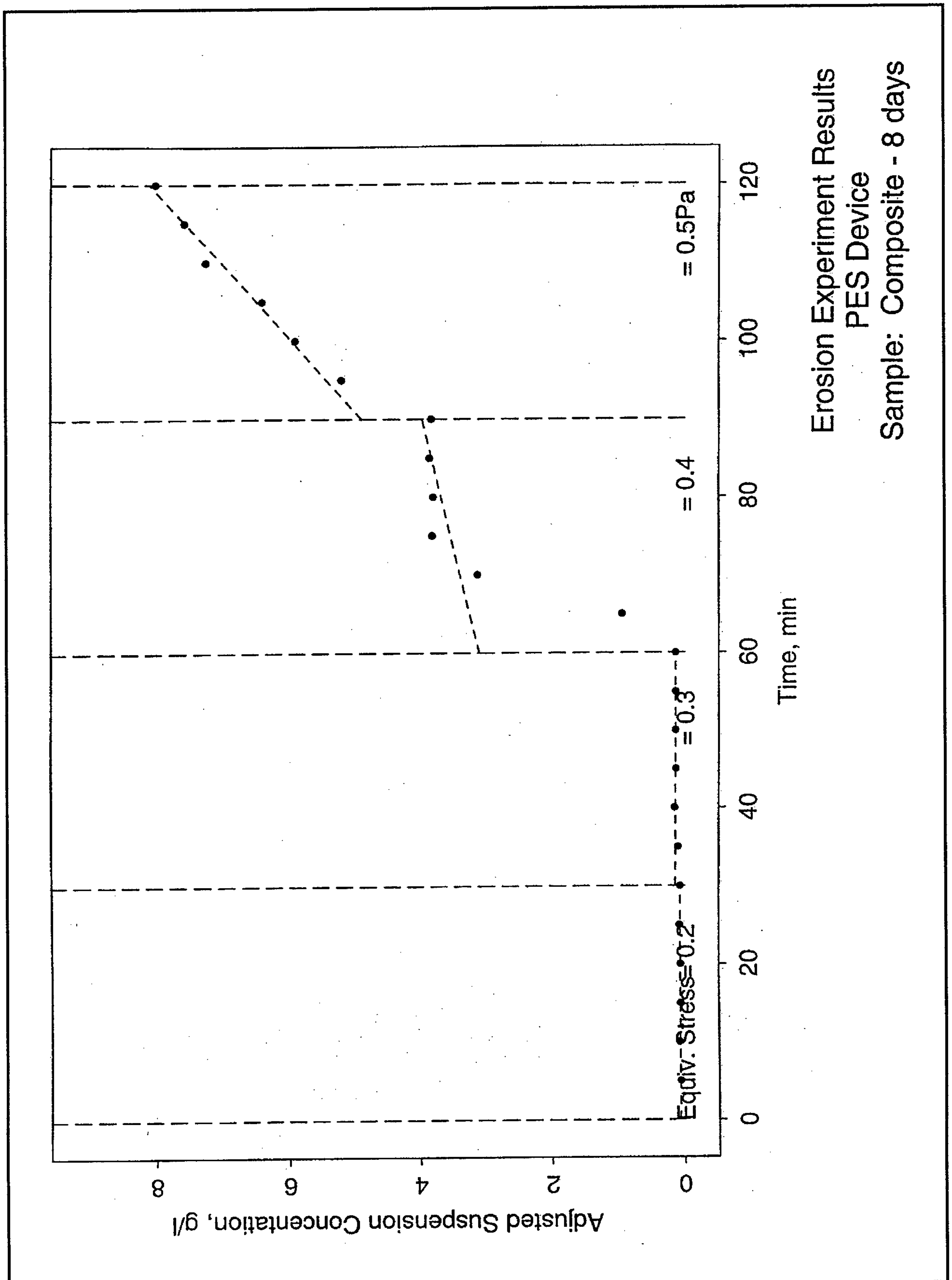
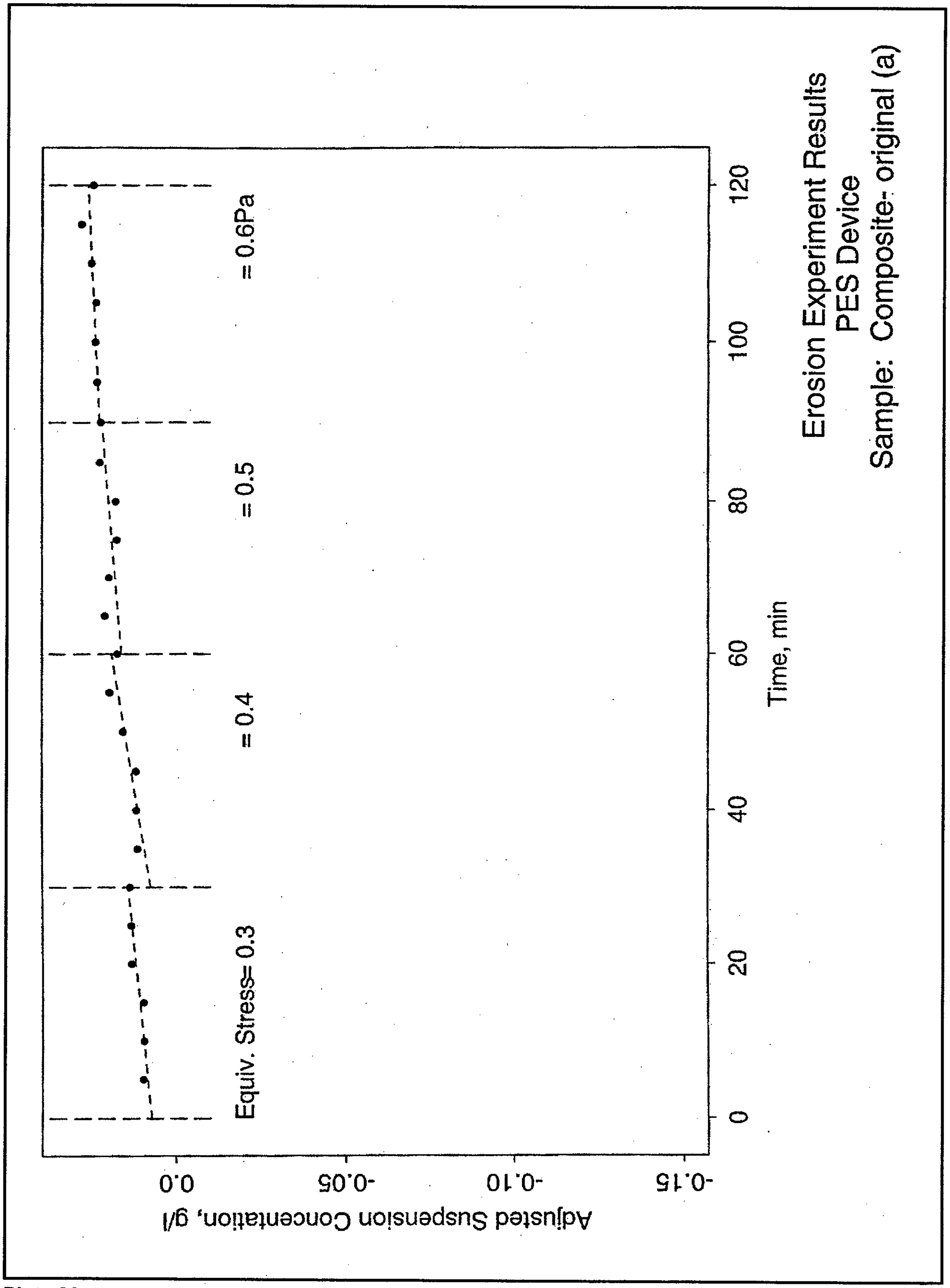

Erosion Experiment Results
PES Device
Sample: Composite - 7 days
Adjusted Suspension Concentation, g/l
Time, min
Equiv. Stress=0.2
= 0.3
= 0.4
= 0.5Pa
0
2
4
6
8
0
20
40
60
80
100
120

Plate 24



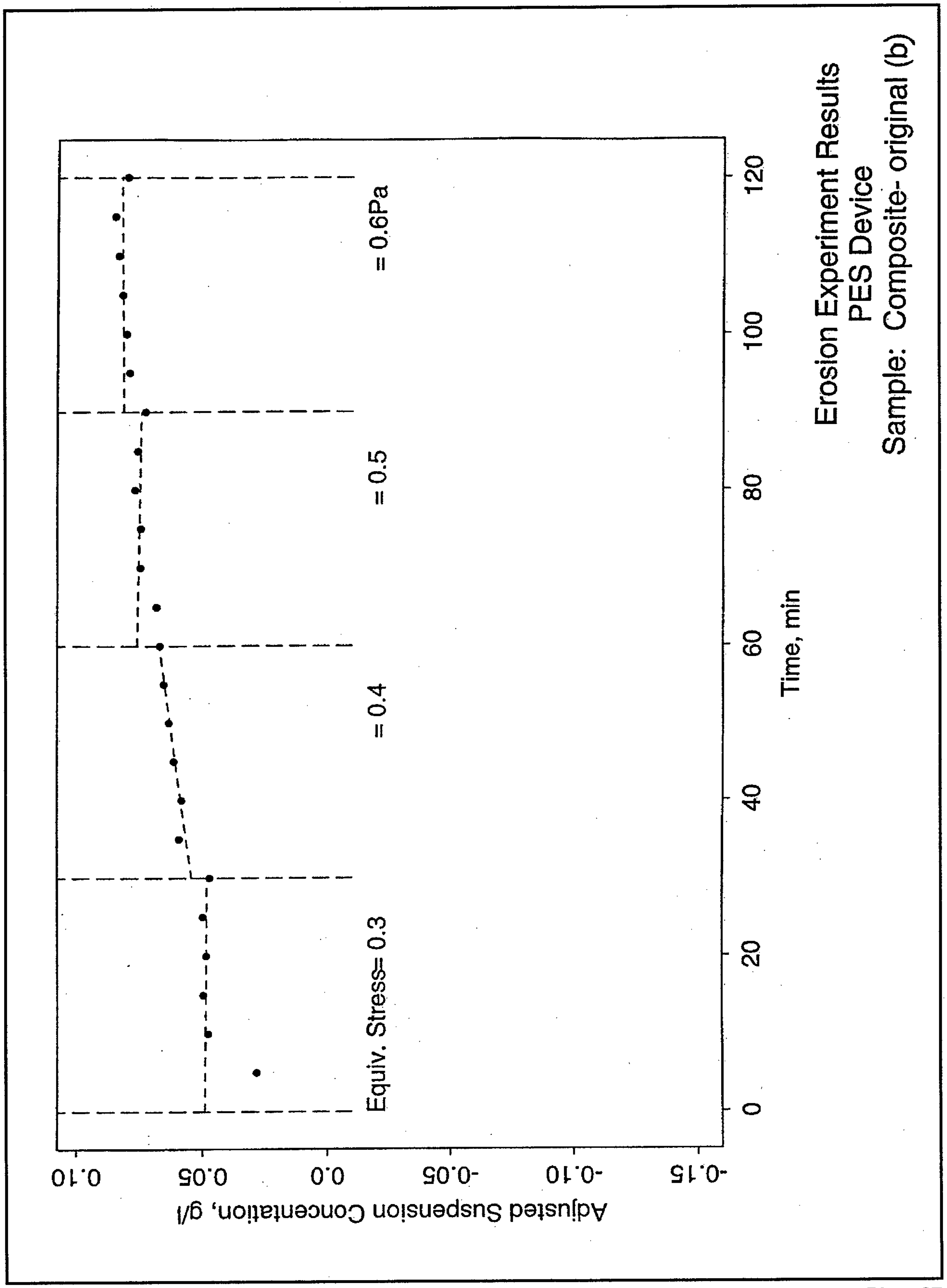
Erosion Experiment Results
PES Device
Sample: Composite - 8 days
Adjusted Suspension Concentation, g/l
Time, min
Equiv. Stress=0.2
= 0.3
= 0.4
= 0.5Pa
0
2
4
6
8
0
20
40
60
80
100
120

Plate 25

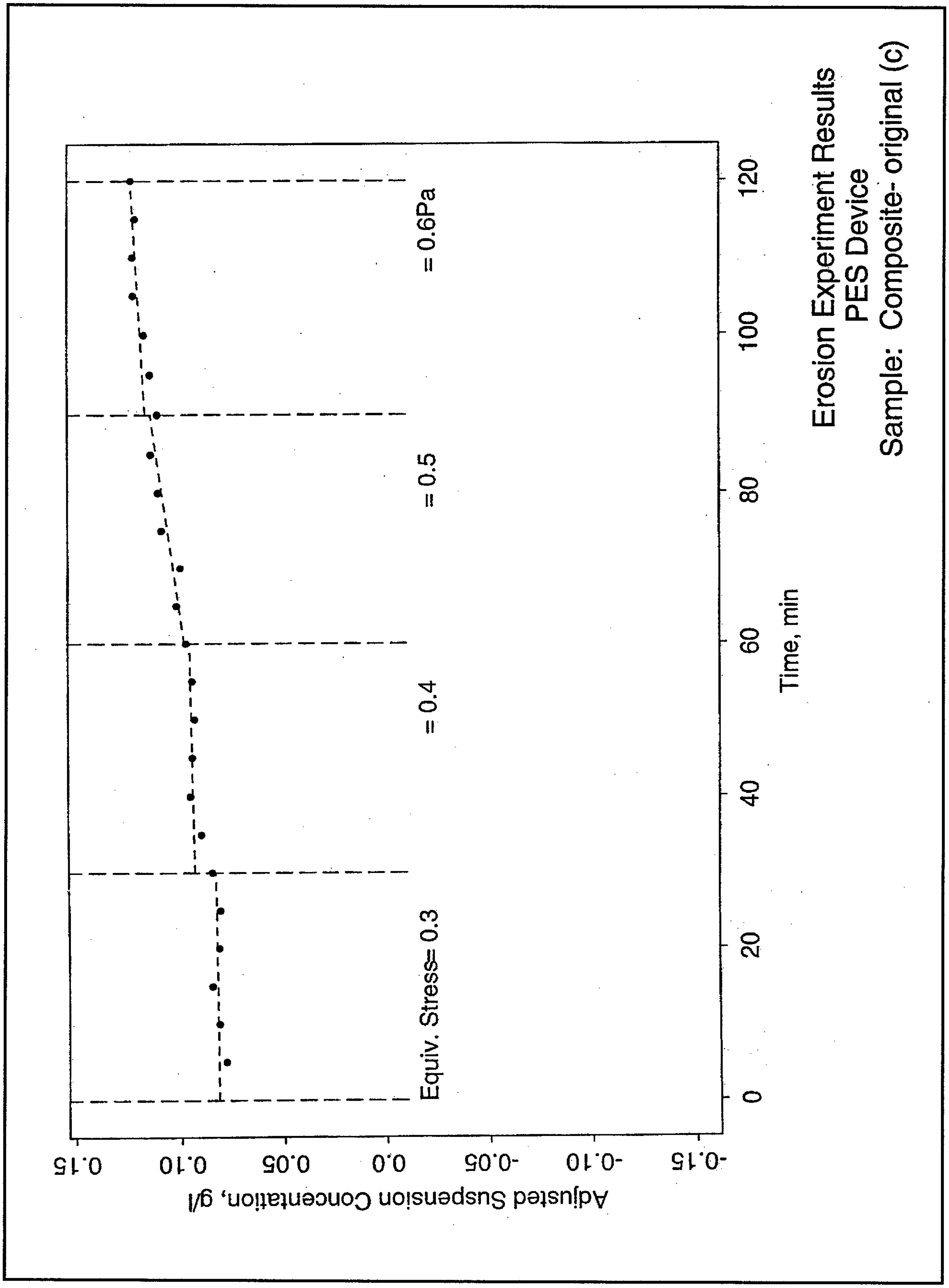


Erosion Experiment Results
PES Device
Sample: Composite- original (a)
Equiv. Stress= 0.3
= 0.4
= 0.5
= 0.6Pa
Time, min
0
20
40
60
80
100
120
Adjusted Suspension Concentation, g/l
0.0
-0.05
-0.10
-0.15

Plate 26



Erosion Experiment Results
PES Device
Sample: Composite- original (b)
Equiv. Stress= 0.3
= 0.4
= 0.5
= 0.6Pa
Time, min
0
20
40
60
80
100
120
Adjusted Suspension Concentation, g/l
0.10
0.05
0.0
-0.05
-0.10
-0.15



Erosion Experiment Results
PES Device
Sample: Composite- original (c)
Adjusted Suspension Concentation, g/l
Time, min
Equiv. Stress= 0.3
= 0.4
= 0.5
= 0.6Pa
0.15
0.10
0.05
0.0
-0.05
-0.10
-0.15
0
20
40
60
80
100
120

Plate 28

REPORT DOCUMENTATION PAGE

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13. ABSTRACT *(Maximum 200 words)*
Several numerical models (CH3D-WES, MDFATE, STFATE, SURGE, and CEQUAL-ICM) have been employed to provide information on potential losses of dredged material proposed to be placed at Site 104 in the Upper Chesapeake Bay and on potential water quality impacts. Placement of the material was assumed to either be from bottom-releasing barges or from hydraulic pump out from a barge with the material released near the bottom.

CH3D-WES is a three-dimensional hydrodynamic model that was employed to provide bottom shear stresses and vertically averaged currents to the MDFATE model. MDFATE computes the building of sediment mounds because of the placement of material at the site and the possible erosion of sediment from those mounds. STFATE computes the fate of dredged material from the moment of its release into the water column until its initial placement on the seafloor. Therefore, STFATE provided estimates of the potential sediment loss to the water column during placement. SURGE was employed to provide insight into the effect of bottom slopes on the extent of bottom surges generated by the impact of the dredged material

(Continued)

14. SUBJECT TERMS

CEQUAL-ICM	Hydrodynamics	Site 104
CH3D	MDFATE	STFATE
Dredged material	Placement	Three-dimensional
Erosion	Sediments	Upper Chesapeake Bay

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striking the seafloor and gravitational forcing. An existing CEQUAL-ICM model of the entire Chesapeake Bay was applied to assess the impact of the placement of dredged material at the site on the water quality of the overlying waters.

Model results show that up to about 17 percent of the placed material could potentially leave the site with bottom release of the dredged material from barges and about 6 percent might potentially leave the site if the material is pumped out of the barge and placed near the seafloor. However, because of factors such as using erosion parameters that are probably slightly larger than would exist for a composite of material from all the proposed dredging sites and using bottom shear stresses that are likely too large, these predicted sediment losses are considered quite conservative. Results from the water quality modeling imply no appreciable impact on the quality of the Upper Chesapeake Bay waters.